ICT, Workforce Age and Firm Performance
Firm-Level Evidence from Germany

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The Faculty of Economics, Business Administration and Information Technology of the University of Zurich hereby authorises the printing of this Doctoral Thesis, without thereby giving any opinion on the views contained therein.

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Mannheim, January 2010 *Jenny Meyer*

Contents

List of Tables

List of Figures

1 Introduction

Information and Communication Technologies (ICT) have diffused into the whole economy. In 2008, 84 percent of the German firms used computers and 79 percent of all firms had Internet access (Statistisches Bundesamt 2008b). This development affects employees and their workplaces. In 2007, 57 percent of the employees in German firms used a computer at their workplace on a regular basis and 48 percent of the employees regularly used a computer with Internet access at their workplace (Statistisches Bundesamt 2007b).

The development and diffusion of ICT has lead to a strand of literature, analysing the economic implications of ICT and their diffusion. ICT as general purpose technologies (Bresnahan and Trajtenberg 1995) have been recognised as a key factor for competitiveness, since ICT enhances firm productivity (Draca, Sadun, and van Reenen 2007). The positive relationship between ICT and productivity is more pronounced if ICT usage is complemented by appropriate organisational measures (e.g. Black and Lynch 2001, Bresnahan, Brynjolfsson, and Hitt 2002, Bertschek and Kaiser 2004). This discussion is mainly related to decentralising organisational measures, implying a greater involvement of employees in decision-making processes and more responsibilities for employees. Some examples are team work, flat hierarchies, autonomous working groups or incentive pay. The implications of ICT diffusion for employees are discussed in the skill-biased technological change literature (e.g. Card and DiNardo 2002, Chennells and van Reenen 2002, Spitz-Oener 2006), showing that the use of new technologies generally increases skill requirements.

Besides the qualification, ICT and their diffusion are also related to the age of people. The probability and frequency of ICT and software use are not the same for all age groups. Computer and Internet use is still lower among older people. In 2008, 44 percent of the German people being 55 years or older used a computer, compared to more than 90 percent of Germans between 10 and 54 years. In the same year, 36 percent of the Germans aged 55 or older used the Internet compared to 87 percent of the Germans between 25 and 54 years and 95 percent of the younger ones (Statistisches Bundesamt 2009a). This distribution of ICT usage also applies to the working world. In 2008, 28 percent of the individuals from 55 to 64 years used a computer at their workplace, whereas more than 50 percent of the people in each of the age groups between 25 and 54 years do so. Considering the Internet use at the workplace exhibits a similar picture: 20 percent of the people between 55 and 64 years compared to 39 to 47 percent of the individuals in the age groups from 25 to 54 years use Internet at their workplace (Statistisches Bundesamt 2008a). Furthermore, there is empirical literature suggesting that older workers have lower ICT skills compared to younger workers and a lower level of mastery of equipment and software (e.g. de Koning and Gelderblom 2006, Tijdens and Steijn 2005).

Due to the demographic development which is characterised by an increasing life expectancy and a simultaneous decrease in birthrates, the labour force participation rate of older people is increasing. In Germany, the labour force participation rate of people between 55 and 60 has increased by 8.6 percentage points from 2000 to 2007, reaching a level of 74.6 percent. The labour force participation rate of people between 60 and 65 has even increased by 14.6 percentage points in the same period, reaching a level of 36.1 percent (Statistisches Bundesamt 2009a).

These developments present a great challenge for the whole economy and the firms in particular. On the one hand, they have to keep pace with the technological development by constantly adopting and using new and improved ICT and software to stay competitive. On the other hand, they have to integrate the aging workers, although they have a lower computer literacy, even nowadays.

Besides the positive contribution of ICT to firm productivity, ICT can also support or enable innovation activities. This applies, in particular, when ICT are used for the knowledge management where they allow to pool and manage internal knowledge as well as to gain access to external knowledge of customers, suppliers or competitors. In this framework, recent Internet technologies and web-based applications, frequently described with the headword web 2.0 might play an important role. Social software as part of web 2.0 serves in particular the communication, cooperation and information sharing between individuals and includes applications such as blogs, wikis or online communities. Common to all of these applications is that they are web-based and self-organising. Social software interlinks users and their knowledge and pursues the open content principle. Due to its characteristics, social software can be applied, amongst others, in the knowledge management. There, it creates knowledge transparency and new knowledge and supports knowledge exchange via faster access to information, more efficient communication and appropriate tagging and linking. Thus, social software has the potential to support the innovative capability of firms.

Continuous innovation is by all means important for the competitiveness of firms and the economy as a whole, creating economic growth and wealth. This does not only hold for innovation in the manufacturing sector, but for service innovation as well. All the more since the importance of the service sector has increased since the 1970s. The contribution of the service sector to the gross value added has increased by 21 percentage points from 1970 to 2008, reaching a level of 69.3 percent. The share of employees being employed in the service sector has even increased by 27.4 percentage points in the same period and adds up to 72.5 percent in 2008 (Statistisches Bundesamt 2009b). The German innovation survey, conducted by the Centre for European Economic Research (ZEW) shows that in particular ICT and knowledge-intensive services are the drivers of innovation in the service sector. In 2007, 54 percent of the firms in these sectors were successful innovators compared to 57 percent in the manufacturing industries and 28 percent in other services (Aschhoff, Doherr, Köhler, Peters, Rammer, Schubert, and Schwiebacher 2009).

The aim of this thesis is to shed some light on the relationship between ICT, workforce age and firm performance. Therefore, the first part of this thesis analyses the relationship between older workers, ICT and productivity. The second part attempts to identify the impact of ICT on service innovation. The second chapter starts with the analysis on how the age structure of the workforce is related to the probability of technology and software adoption. The third chapter continues by exploring the relationship between older workers and productivity enabled by ICT. In the fourth chapter, the impact of social software, as part of the recent web 2.0 technologies, on service innovation is analysed. Final remarks on the managerial and policy implications of the results of this thesis are presented in chapter five.

This thesis contributes to the existing literature in several ways as I will point out in the following descriptions of the second, third and fourth chapter. The second chapter “Workforce Age and Technology Adoption in Small and Medium-Sized Service Firms” deals with how the age structure of the workforce is related to the probability of technology adoption in small and medium-sized service firms. It takes into account the age of the workforce, measured by the share of employees in four different age groups and the age dispersion within the workforce, represented by a weighted Herfindal index calculated from these age groups. Moreover, it attempts to identify the role of teamwork as workplace practice in the relationship between workforce age and technology adoption. To the best of my knowledge, there is no empirical study analysing the impact of an aging workforce or of the workforce’s age dispersion on technology adoption at the firm-level in service industries. Furthermore, taking into account the role of teamwork in this context has not been done before and therefore, a research gap is closed.

The analysis of the second chapter is based on firm-level data of 356 small and medium-sized firms of the ICT- and knowledge-intensive services sector. The empirical results reveal that compared to employees being younger than 30 years, an older workforce is negatively related to the probability of adopting new technologies in the analysed firms. The dispersion of the employees’ age within the workforce is not connected with the probability of technology adoption. However, in firms that intensified teamwork, a workforce being homogenous in terms of age is positively related to the probability of adopting new technologies.

The third chapter, “Do Older Workers Lower IT-Enabled Productivity” takes account for the productivity enabling character of ICT. It analyses the interplay between ICT, older workers and labour productivity. The contribution of this chapter is that it relates firm productivity to the use of ICT *and* to the age structure of employees, which has not been done before. On the one hand, the productivity studies that focus on the effects of the age structure of employees do not consider ICT as a further production factor. On the other hand, studies that find empirical evidence for positive productivity effects of ICT at the firm level do not consider the age structure of the workforce. This chapter attempts to close this gap by considering both ICT and the age structure of the workforce using two waves of a firm-level data set.

In the third chapter, a production function approach with heterogenous labour is applied to a firm-level data set from the German manufacturing and services industries. It comprises data from 1039 firms observed in the years 2004 and 2007. The analysis shows that employees aged younger than 30 years are significantly less productive than prime age employees, whereas employees being older than 49 do not differ significantly from prime age employees between 30 and 49. Older computer users are significantly more productive than older non-computer users. The significantly positive relationship between labour productivity and IT intensity is not affected by the proportion of older employees implying that older employees do not lower IT-enabled productivity.

The fourth chapter, "Does Social Software Support Service Innovation", analyses how social software applications are related to the probability of service innovation. The focus is on how social software and its implementation in the knowledge management supports the management and pooling of internal knowledge and the access to external knowledge, which in turn belong to the main inputs to service innovation. Internal and external knowledge are different knowledge sources and might also differ in their impact on stimulating innovative activities. Therefore, in a second step, a differentiation between social software use for internal or external purposes is made to detect these possible differences. Up to now, there is only some case study evidence on the adoption of social software, mainly wikis and blogs, in the knowledge management of several firms (e.g. Müller and Dibbern 2006, Ehms 2008, Hilzensauer and Schaffert 2008). However, these studies do not consider the impact of social software in the knowledge management on innovation. To the best of my knowledge, none of the studies analyzing the relationship between knowledge management and innovation considers social software as a knowledge management tool. The studies which analyse the employment of information technology in knowledge management and collaboration and its relation to innovation and product development are based on theoretical considerations, case studies or use cases (see for instance Adamides and Karacapilidis 2006, Christensen, Magnusson, and Zetherstrom 2006, Sethi, Pant, and Sethi 2003). Therefore, this chapter closes a research gap by being the first paper that provides empirical evidence on the use of social software as a knowledge management tool and its impact on service innovation.

In the fourth chapter, a knowledge production function (Griliches 1979, Pakes and Griliches 1984) in which the application of social software constitutes the knowledge sourcing activity serves as theoretical framework. The analysis is based on data from 505 German ICT and knowledge-intensive service firms. The results of the fourth chapter reveal that ICT and knowledge-intensive service firms using social software are more likely to innovate. Taking into account former innovative activities of the firm and its previous propensity to adopt new technologies and to change processes, the analysis suggests a causality between social software use and innovation that runs from social software to service innovation. However, the econometric analysis exploring the differences between the knowledge sourcing activity with focus on internal and external knowledge, represented by the social software use for internal and external purposes, yields no robust results. Thus, the analysis allows no statement on whether there are differences between internal and external knowledge and their impact on service innovation.

2 Workforce Age and Technology Adoption in Small and Medium-Sized Service Firms*

2.1 Introduction

Today's demographic development is characterised by an increasing life expectancy and a simultaneous decrease in birthrates. The employment rate of individuals between 55 and 64 years has increased, particularly during the last five years. In the EU-25 the employment rate of this age group increased by 5.9 percentage points from 2000 to 2005 and amounted to about 42 percent in 2005. In the same time period the labour force participation of individuals between 15 and 24 years decreased by about 1.3 percentage points (Eurostat 2007). This development has two implications. Firstly, the working population is getting older and secondly, the composition of the workforce in terms of age is changing. Small and medium-sized firms with up to 249 employees constituted about 99.3 percent of the German economy in the year 2005 (Kless and Veldhues 2008). Therefore, the pronounced demographic change and its consequences for small and medium-sized firms concern the whole German economy and its competitiveness.

In an economy where knowledge is a production factor of increasing importance and where information processing is based on information and communication technologies (ICT), an efficient relationship between human capital and ICT usage is crucial for the performance and competitiveness of firms. This particularly

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applies for knowledge-intensive service providers (e.g. tax consultancy and accounting, architecture) and for information and communication technology service providers (e.g. software and IT services, telecommunication services).[1] The first reason is the intensive use of ICT in these sectors, which rely on a continuous adoption of new technologies and software. The second reason is that for these firms the structure, quality and internal organisation of human capital are exceptionally important aspects in the production of the services they provide.

The rapid technological progress and the fast depreciation of knowledge on the one hand and the demographic development on the other hand present a great challenge for these firms. Empirical evidence indicates that older workers are less likely and less qualified to use ICT compared to younger employees (e.g. de Koning and Gelderblom 2006, Schleife 2006). Small and medium-sized firms have smaller internal labour markets. An internal labour market generates among others long tenure, promotion and pay by seniority (Siebert and Addision 1991). These are job attributes being attractive to employees. Consequently, small and medium-sized firms might be less attractive to employees due to the smaller or non-existing internal labour markets. Hence, small and medium-sized firms might be hit by demographic changes more directly. Therefore, understanding the relationship between the age composition of the workforce and technology adoption is important for small and medium-sized firms.

Using firm-level data of 356 small and medium-sized firms of the ICT- and knowledge-intensive services sector, this paper provides empirical evidence on the relationship between the employees' age and its dispersion within the workforce, and the probability of adopting new or significantly improved technologies. Moreover, it attempts to identify the role of teamwork as workplace practice in this relationship.

The econometric results show that compared to employees being younger than 30 years an older workforce is negatively related to the probability of adopting new technologies in small and medium-sized service firms. The dispersion of the

[1] These sectors contribute to about eight percent of the German sales (Statistisches Bundesamt 2006).

employees' age within the workforce is not connected with the probability of technology adoption. However, in firms that intensified teamwork, a homogenous workforce in terms of age is positively related to the probability of adopting new technologies.

This paper is organised as follows: The second section reviews the background discussion in the existing economic literature and derives the hypotheses. Section three presents the data, the estimation strategy and some descriptive statistics. In the fourth section the empirical results are presented. Section five concludes and gives an outlook on further demands on research.

2.2 Background Discussion and Hypothesis Derivation

This paper focuses on the relationship between the age structure of the workforce and the adoption of new or significantly improved technologies or software in small and medium-sized ICT and knowledge-intensive service providing firms in Germany. The ICT-intensive service providers include the branches software and IT services, ICT-specialised trade and telecommunication services. The knowledge-intensive service providers comprise the sectors tax consultancy and accounting, management consultancy, architecture, technical consultancy and planning, research and development as well as advertising. The latter ones and the ICT-specialised trade are characterised by a high IT intensity, but are not necessarily highly innovative. For these sectors a constant adoption of new IT and software is important. Furthermore, the paper takes the enhancement of teamwork as a tool of innovative workplace organisation into account. It is related to several strands of the literature.

To the best of my knowledge, there is no empirical literature analysing the impact of an aging workforce on technology adoption at the firm-level in service industries. However, there are some firm-level studies showing that the use of new technologies is negatively related to the proportion or wage-bill share of older workers in firms (Bertschek 2004, Aubert, Caroli, and Roger 2006, Beckmann 2007). According to the Oslo Manual (OECD/Eurostat 2005), "a process innovation is the implementation of a new or significantly improved production or delivery method".

This includes significant changes in equipment, techniques and/or software (OECD/Eurostat 2005). Thus, technology adoption can be seen as an example of process innovation. Therefore, the literature on older workers and process innovations can be considered to give a hint at the relationship between older workers and technology adoption at the firm-level. However, there are only few empirical analyses and they use data from manufacturing firms. Rouvinen (2002) analyses the characteristics of process innovations in the Finnish manufacturing sector. He finds that an increasing average age of the employees, although he uses this variable as proxy for firm age, reduces the probability of process innovation. Nishimura, Minetaki, Shirai, and Kurokawa (2004) investigate the interaction between age and the qualification of the employees and its impact on technological progress in Japanese industries. Using only a small sample, they find no significant impact of older workers (above 40 years) with a high qualification (share of old workers with high education in the total labour inputs) on the rate of technological progress in non-manufacturing industries. However, they find that the share of older workers with a high qualification reduced the rate of technological progress in the manufacturing industries in the 1990s. Schneider (2008) uses a linked employer-employee approach to analyse the impact of the age structure of the workforce on product innovations of German manufacturing firms. He finds significant effects of the age structure of the workforce on the technological innovativeness and an inverse u-shaped age innovation profile.

There are several studies using individual data which show that older workers are less likely and less qualified to use ICT compared to younger employees. Friedberg (2003) analyses the relationship between computer use at work and the age of the workers by using individual data on American workers in the year 1993. Her results reveal that workers who are younger than 60 years use a computer more often than workers who are older than 60 years. Using individual-level data from 1997 of German male workers, Schleife (2006) finds that the probability of computer use among workers aged between 55 and 64 years is significantly lower than that of workers between 25 and 34 years. Borghans and ter Weel (2002) and de Koning and Gelderblom (2006) focus on the computer skills and the used ICT applications instead of the simple computer usage. Borghans and ter Weel (2002) show in their analyses that the computer skills of younger employees are better than those of older workers. They use British data from 1997. Using data from 2001, de Koning and Gelderblom (2006) show that the probability of using complicated ICT applications at work is lower among workers above 50 years. Today, however, most employees, especially in ICT and knowledge-intensive service firms, use computers at work. Nevertheless, computer experience does not automatically lead to computer expertise, as has been found in a psychological study by Arning and Ziefle (2008). Tijdens and Steijn (2005) use individual data from 2002 and find that older workers have a lower level of mastery of equipment and software. Since ICTs are constantly developing and new applications and software occur regularly, employees need to adapt to these new technologies and applications. To the best of my knowledge, there is no recent economic literature analysing the relationship between older workers and recent ICT-applications. These makes the findings of Borghans and ter Weel (2002) and de Koning and Gelderblom (2006) especially important. Since ICT applications become more complicated and require advanced ICT skills, their results suggest that the relationship between older workers and ICT remains difficult.

The relationship between technological change and ICT on the one hand and older workers on the other hand is explained by two main reasons: (1) the depreciation of human capital. Within technological change and innovation, human capital may become obsolete. Thus, older workers may resist innovation when their human capital might be depreciated. Consequently, they tend to retire earlier. Using two data sets from the U.S., Friedberg (2003) states that the less frequent use of computers by older workers is related to their imminent retirement. Investing in their computer skills does not pay off any longer. Friedberg (2003) finds that computer users tend to retire later than non-users which is probably due to comparative advantages and because they are willing to invest in training. Furthermore, her results reveal that the less frequent use of computers by older workers can be explained by the differences according to occupations and education. Empirical evidence for Germany found by Schleife (2006) suggests that age does not play a significant role in the retirement decision when other factors such as qualification, work experience, etc. are considered. Borghans and ter Weel (2002) even find that the imminent retirement of older workers is no significant parameter affecting the non-use of computers. (2) The so-called "deficit model" explains the process of aging from a gerontological point of view. This model assumes that older people lose important skills, showing shortcomings and deficits compared to younger ones. This affects physical (declining physical strength or decelerated reactions) and mental skills (cutback of brainpower, especially of fluid brainpower which is needed amongst others for new solutions and a fast processing of information (Börsch-Supan, Düzgün, and Weiss 2006)) as well as limited interests and reduced social activities (Walter 1995). Most dimensions of physical performance decline constantly beyond the age of 30 to 35 for virtually all types of measures (Stones and Kozma 1985). Some aspects of cognitive decline already begin in healthy educated adults when they are in their 20s and 30s (Salthouse 2009). The deficit model can be related to the economic context and the labour market. Asked what kind of attributes emerge in which age group and how important they are, personnel officers reply that in general older workers show a lower learning aptitude, a lower willingness to learn or flexibility compared to younger workers (Boockmann and Zwick 2004). These skills, however, are especially important for the implementation of new technologies or software. The decrease in physical and mental skills, inhibited in the deficit model, can also be related to computer use. Psychologists find that there are significant age differences in computerized information retrieval response times (Westermann, Davies, Glendon, Stammers, and Matthews 1995) and lower computer task performance of older people (Czaja 2001).

Considering that older workers are negatively related to technological change and the use of ICT leads to the first hypothesis:

Hypothesis 1 *An older workforce is negatively related to the adoption of new technologies.*

Another important strand of literature focuses on the age dispersion within the workforce. As Lazear (1998) already states, there are complementarities between the human capital of younger and older workers. Younger employees are more comfortable with the use of ICT and older employees are more experienced, have a better knowledge of the intra-firm structures and the operating process. Therefore, the complementarities between older and younger workers can be effective, especially in the case of adopting new technologies or software in the process of service creation. Workers younger than 30 years have a high productivity and a high potential in terms of mastering equipment and software (Tijdens and Steijn 2005). Moreover, the knowledge of this age group may still be up to date as their educational achievement is recent. The motivation and the attitude towards using technology (Morris and Venkatesh 2000) of younger workers can lead to spill-over effects. Younger employees can help older ones by explaining to them the innovations and at the same time sharing their enthusiasm with them. Empirical evidence on the success of age-mixed teams can be found in the analysis of Grund and Westergard-Nielsen (2008). In a different context, they find an inverse u-shaped relation between the average age of the employees and its standard deviation and firm productivity. This means it is better to have a heterogenous workforce than a homogenous one, as long as it is not too heterogenous. Pelled, Eisenhardt, and Xin (1999) find a positive interrelation between age heterogeneity and group performance by analysing 45 teams of 3 firms, although the group performance is only evaluated by the team manager. This is supported by Kilduff, Angelmar, and Mehra (2000) who use data of 159 managers playing a business game. Simons, Pelled, and Smith (1999), however, reveal the opposite: They find a negative relationship between heterogeneity in terms of age and the growth of sales analysing data of 57 manufacturing firms.

Considering the theoretical considerations on the complementarities between the human capital of older and younger workers and the empirical evidence on age heterogeneity and the success of age-mixed teams lead to the following two hypotheses:

Hypothesis 2 *The age dispersion within a workforce is positively related to the probability of technology adoption.*

Hypothesis 3 *Age-mixed teams are positively related to the probability of technology adoption.*

2.3 Data and Estimation Strategy

The data used for the empirical analyses of the three hypotheses is taken from the quarterly business survey among the "service providers of the information society" conducted by the Centre for European Economic Research (ZEW) in cooperation with the credit rating agency Creditreform. The sector "service providers of the information society" comprises nine industries belonging to the information and communication technology service providers (e.g. software and IT services) and the knowledge-intensive service providers (e.g. tax consultancy and accounting).

Every quarter, a single-page questionnaire is sent to about 3,500 mostly small- or medium-sized firms. At each wave, the survey achieves a response rate of about 25%. It is a random sample, stratified with respect to firm size (3 size classes: 1-19 employees, 20-59 employees, 60 and more employees), region (East/West Germany) and sector affiliation.[2] The questionnaire is divided into two parts. In the first part, firms assess their current business development with respect to the previous quarter as well as their expectations for the next quarter. The second part is dedicated to questions concerning current economic issues, ICT diffusion or particular information about the firms e.g. their innovative activities or training behaviour. The questions of the second part change quarterly with selected questions being repeated annually. The survey is designed as a panel.[3] This paper uses the data of the 46th wave (3rd quarter 2005).[4] Due to item non-response for the age groups and the technology adoption variable, the number of observations is reduced, and thus the final data set comprises 356 firms with at least 2 and at most 250 employees.[5]

Former waves of the data have previously been used to analyse the productivity effects of organisational change (Bertschek and Kaiser 2004) and the relationship between managerial ownership and firm performance (Müller and Spitz-Oener 2006).

The adoption of new or significantly improved technologies and software is represented by a dummy variable.[6] The dummy variable takes on the value one if

[2]For further details on the nine industries, their industrial classification and their distribution within the sample, see the appendix and Table 2.4 in the appendix.

[3]Although the question concerning technology adoption was asked for the fourth time, panel data estimations cannot be provided. The survey among “service providers of the information society” is a very versatile data set where firms participate on an irregular basis. The use of the panel data causes a great loss of observations, and unobserved heterogeneity could not be taken into account because there is only a very tiny fraction of firms for which data are available for more than two subsequent periods.

[4]The 46th wave of the survey includes information on the age structure of the workforce, the qualification level of the employees, the implemented process, product and organisational innovations, the export activity and the existence of foreign competitors.

[5]Firms with less than 2 employees are ignored in the analysis since the variable teamwork is not relevant for them. Thus, including them would bias the sample.

[6]The firms answered the following question: Did you adopt new or significantly improved technologies in the last 12 months (e.g. new electronic data processing systems, Internet)?

the firm adopted new technologies in the last twelve months and zero if not.

As the dependent variable is a dummy variable and I assume the error term to be normally distributed, a Probit model is used for the empirical analysis.[7]

The main explanatory variables are the employees' age and its dispersion within the workforce. The age of the employees is represented by four age groups (share of employees younger than 30 years, between 30 and 40 years, between 40 and 55 years and older than 55 years).[8] The age dispersion is constituted by a weighted Herfindahl index, measuring the concentration of the employees' age in the firm. The Herfindahl index usually lies between zero and one, with zero representing a minimal concentration and one representing a maximal concentration. The shares of the employees in the four age groups are used to calculate the Herfindahl index. This Herfindahl index is weighted by 0.75 if the firm has only employees in two of the four age groups and zero employees in the group 30 to 40 years or 40 to 55 years, weighted by 0.5 if the firm has only employees in two of the four age groups and zero employees in the group 30 to 40 years and 40 to 55 years (this case does not exist in the data) and weighted by 0.875 if the firm has only employees in three of the four age groups and zero employees in the group 30 to 40 years or 40 to 55 years.

Note, however, that there might be an endogeneity problem. The age of the workforce may be endogenous due to selection. On the one hand, companies might dismiss older workers who are not productive and adaptive enough by early retirement programs, for instance. On the other hand the firms might hire younger workers who are more comfortable with the use of ICT and more flexible regarding new technological developments. Otherwise, there might be self-selection when older employees decide to leave the labour market when their workplaces are affected by technological change and if sufficient support by social security systems is available. Due to data limitations this cannot be tested. Considering the development of the percentage shares of older, middle-aged and younger workers

[7] For more details on the Probit model, see Wooldridge (2002). All calculations and estimations of this paper were done with STATA 10.0.

[8] The shares of employees being younger than 25 years and being between 25 and 30 years old have been combined to the group younger than 30 years. They are the reference group.

since 2002 suggests that the age of the workforce can be assumed to be a constant factor that does not significantly change within twelve months. Therefore, three other waves of the business survey among the “service providers of the information society” are used. As Table 3.5 in the appendix shows, the average variation of the share of employees belonging to a certain age group over the time period from 2002 to 2005 is only small. It seems there is no systematic selection mechanism. This is supported by the results of the Kernel density estimations in Figure 2.1 in the appendix as well as by a Kolmogorov-Smirnov test indicating that the distributions of the share of younger, middle-aged and older workers do not differ significantly between two consecutive years. However, this is only a weak invalidation of the endogeneity problem.

Another explanatory variable that is considered in the estimations is the qualification level of the employees, measured by the share of highly qualified employees (university degree or degree of university of applied sciences).[9] On the one hand, there has been a lot of discussion in the literature on skill-biased technological change, suggesting that the use of new technologies and the diffusion of IT change the skill requirements and thus lead to an increase in demand for highly qualified labour (e.g., Chennells and van Reenen 2002, Card and DiNardo 2002). On the other hand, the skill level of workers is one of the important determinants of technology diffusion (Rosenberg 1972). Adoption might be slow if the successful introduction requires complex skills and their acquisition is costly and time-consuming. Consequently, the suitable know-how and the manner in which the necessary skills are acquired determine the diffusion of technology (Hall and Khan 2003). Battisti, Hollenstein, Stoneman, and Wörter (2007), however, find that the impact of the employees' skill level on ICT adoption only applies to inter-firm diffusion but not to intra-firm diffusion. A highly qualified labour force is supposed to facilitate the adoption of new technologies or software.

Enhancement of teamwork in the foregoing three years, represented by a dummy variable, is another explanatory variable. There is a broad range of literature suggesting that the implementation of new IT systems often goes hand in hand with organisational changes in firms (Milgrom and Roberts 1990, Hitt and Brynjolfsson 1997, Bresnahan, Brynjolfsson, and Hitt 2002). The implementation

[9] The share of medium-qualified and unqualified employees are the reference group.

of a new information and communication system or a new software system often requires a restructuring of the firm to use the new system efficiently. This discussion is mainly focussed on decentralising organisational measures which imply a greater involvement of employees in decision-making processes and an enlargement of their responsibilities. Some examples are teamwork, flat hierarchies, autonomous working groups or incentive pay - measures supposed to positively affect the information flow within firms and the motivation of the employees. Thus, IT investments and organisational investments are interpreted as strategic complementarities (Brynjolfsson and Hitt 2000, Bresnahan, Brynjolfsson, and Hitt 2002, Bertschek and Kaiser 2004). The use of innovative workplace practices such as teamwork may provide a better environment for the adoption of new technologies because of the existing complementarities. Battisti, Hollenstein, Stoneman, and Wörter (2007) argue that the profit-seeking firm will most likely adopt ICT once organisational changes have been realised. They find a positive relationship between organisation, covering amongst others teamwork, and ICT adoption. Hollenstein and Wörter (2004) find a negative relationship between insufficient compatibility or problems/costs of reorganisation and the adoption of E-commerce for sales. The adaption of E-commerce can be considered as a proxy for ICT adoption.

There might be potential endogeneity of the teamwork variable because of existing complementarities between organisational structures, such as teamwork, and ICT. However, Battisti, Hollenstein, Stoneman, and Wörter (2007) argue that organisational changes and ICT adoption do not take place simultaneously since a firm is faster in adopting ICT than in changing its organisation. Since the data used here do not offer appropriate instruments to control for this potential endogeneity, a bivariate Probit model is estimated to test for this complementary relationship (Athey and Stern 1998, Cassiman and Veugelers 2006, Edler, Fier, and Grimpe 2008). The bivariate Probit model provides a test for a positive correlation between technology adoption and teamwork conditional on the vector of covariates including the above mentioned explanatory and control variables. Another advantage of using this procedure is that it allows for the age of the employees to be related to teamwork. There is empirical evidence on the relationship between older workers and organisational structures. These studies find that innovative workplace practices, such as teamwork, giving more decision-making authority and responsibility to employees is negatively related to the employment of older workers. Using West German firm level data for the years 1993 to 1995, Beckmann (2001, 2007) finds that organisational changes have significantly negative effects on the percentage share of workers aged 50 or more. Aubert, Caroli, and Roger (2006) provide empirical evidence for France using linked employer-employee data. They find that the more innovative workplace practices are applied in the firm, the lower is the percentage share of older workers.

However, the bivariate Probit model does not account for the joint relation of teamwork and age dispersion, as a proxy for age mixed-teams. Therefore, interactions between the weighted Herfindahl index and the teamwork variable are taken into account. As pointed out by Ai and Norton (2003) the interpretation of marginal effects of interaction terms in nonlinear models such as Probit is not straightforward. For convenience and to simplify the interpretation of the interactions, a Linear Probability model is used for the estimation of the interaction effects on the probability of technology adoption.[10]

A dummy variable for changes in the market or customer requirements in the foregoing three years is included as control variable since service firms, and in particular small and medium-sized firms, are characterised by a high degree of interaction with clients and customers, respectively (Koch and Strotmann 2006). New market developments or changed customer requirements might lead to new or improved services, that is product innovation. These new or improved services, however, might require the use of new technologies or software. Changed customer requirements could also imply a new or different way of the service provision and thus require the adoption of new technologies or software to meet these demands.

Variables for firm characteristics such as firm size (log. number of employees) and firm age (in years) are also included as control variables. Larger firms may profit from emerging economies of scale. There is vast amount of literature confirming the positive relationship between firm size and technology diffusion.[11] Battisti, Hollenstein, Stoneman, and Wörter (2007), however, find that firm size is only related to inter-firm ICT diffusion but not to intra-firm ICT diffusion. Moreover, it

[10]For more details on the Linear Probability model see Wooldridge (2002).

[11]See for example Karshenas and Stoneman (1995) for a summary.

seems that the role of firm size differs with respect to the purpose of ICT adoption. Hollenstein and Wörter (2004) find a positive effect of firm size on the adoption of E-commerce for purchase, but no significant effect on the adoption of E-commerce for sales. Older firms, on the one hand, may be more traditional than their younger counterparts and therefore less inclined to change the operating process and adopt new technologies. On the other hand, older firms may have more experience in changing processes and adopting new technologies. Furthermore, they may have a higher need to adopt new technologies since their equipment might be outdated, compared to younger firms which might have employed the latest technology during their foundation. Hollenstein and Wörter (2004) find no impact of the firm age on adoption of E-commerce for sales and a negative relationship between firm age and the adoption of E-commerce for purchase. Additionally, the variable firm age is supposed to control for the tenure of the employees, since employees age with the firm they work in.

A dummy variable for exporting activities and a dummy variable for foreign competition (as proxy for competition) are included. Exporters may depend on the latest communication technologies in order to stay in contact with their customers abroad. Borghans and ter Weel (2006) find at least a positive relationship between having parts of the production exported and the relative pace of computer adoption. A high competition may force firms to be efficient and thus to adopt new technologies or software to reduce costs or to accelerate the service production process. The empirical evidence suggests that the type of competition matters. Borghans and ter Weel (2006) find a positive relationship between competition and the pace of computer adoption with regard to competition on high quality, good services and product advancement. Hollenstein and Wörter (2004), however, find no significant impact of competition intensity on the adoption of E-commerce for sales, but a positive one on the adoption of E-commerce for purchase.

A dummy variable for product innovation is additionally considered. Firstly, as suggested by Battisti, Hollenstein, Stoneman, and Wörter (2007), innovative firms may have a greater absorptive capacity for new technologies. Secondly, the introduction of a new or significantly improved service may lead to a change in the operating process and therefore to the adoption of new technologies. Furthermore, including product innovation controls for a generally higher willingness of the firm to innovate or renew the operating process itself. On the other hand, product innovations and process innovations (and technology adoption as an example of process innovation) in the services sector cannot be easily distinguished. A process innovation, such as the adoption of new or significantly improved technologies, allows to improve the quantity or quality of a provided service by keeping the input constant, reducing the supply costs or accelerating the process (Hempell 2003). This change in the provided service, caused by a process innovation, can in turn be interpreted as product innovation. The data do not offer appropriate instruments to control for endogeneity or simultaneity problems arising in this context. The empirical evidence on the relationship between product innovation and ICT or computer adoption, however, is not that clear. Hollenstein and Wörter (2004) find a positive relationship between the introduction of innovations and the adoption of E-commerce. Battisti, Hollenstein, Stoneman, and Wörter (2007) find that this positive relation applies only to intra-firm ICT diffusion and not to inter-firm ICT diffusion. And Borghans and ter Weel (2006) even find a negative effect of the involvement in R&D projects and the pace of computer technology adoption. Nevertheless, product innovations are supposed to be positively related to the probability of technology adoption.

Nine sector dummies are considered to control for industry-specific fixed effects.[12] A dummy variable for East Germany is incorporated to account for potential regional differences.

Table 2.1 depicts some descriptive statistics of the variables used for the sample where item non-response for technology adoption and the age of workforce is excluded. On average, half of the firms (about 51 percent) in the sample have adopted new or significantly improved technologies. The share of employees being older than 55 years is about 11 percent. The major share of employees is middle-aged (about 67 percent). The weighted Herfindahl index is about 0.41, which indicates that the employees' age within the firms is rather dispersed. On average, the share of highly qualified employees is about 38 percent. About 68 percent of the firms faced a change in customer or market requirements. The average firm in the sample has about 37 employees and is about 16 years old. More than half of the firms have foreign competitors in their market (about 53

[12]The sector marketing represents the reference category.

percent). About 35 percent of the firms are exporters. About 51 percent of the firms in the sample introduced service product innovations.

Table 2.1: Descriptive Statistics: Total Sample

Variable	Mean	Std. Dev.	Min.	Max.	N
technology adoption	0.511	0.501	0	1	356
share of empl. 30 - 40 years	0.326	0.187	0	1	356
share of empl. 40 - 55 years	0.342	0.201	0	1	356
share of empl. > 55 years	0.11	0.129	0	0.667	356
weighted Herfindahl index	0.408	0.131	0.255	1	356
share of highly qualified empl.	0.378	0.290	0	1	356
enhancement of teamwork	0.399	0.490	0	1	321
change customer requirements	0.676	0.469	0	1	318
firm size (number of employees)	36.831	48.379	2	250	356
firm age	15.906	10.406	1	86	351
foreign competitors	0.527	0.5	0	1	330
exporter	0.352	0.478	0	1	347
product innovation	0.505	0.501	0	1	319

Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

2.4 Empirical Results

The results of the Probit estimations considering the four age groups of employees are depicted in Table 2.2. The Table reports the average marginal effects (sample averages of the changes in the quantities of interest evaluated for each observations).[13] Specification (1) shows the raw effects of the age groups. Compared to the share of employees younger than 30 years, the share of employees older than 30 years is negatively related to the probability of adopting new or significantly improved technologies. Furthermore, the increase of the magnitude of the marginal effect from the share of employees between 30 and 40 years to the share of employees older than 55 years shows that the older the workforce, the less likely is the adoption of new technologies. Table 2.2 shows that firms with a higher share of employees between 30 and 40 years have a lower probability to adopt new

[13]Since the estimated coefficients in a Probit model only allow to make a statement on the significance and the sign of an effect but not on its extent, only the marginal effects will be discussed in the following. Table 2.6 in the appendix shows the coefficients of the Probit estimations.

technologies compared to a high share of employees being younger than 30 years. The marginal effect is -0.315 (see second column of Table 2.2). The share of employees between 40 and 55 years and the share of employees older than 55 years is also negatively related to the probability of introducing new technologies. The average marginal effect is -0.381 and -0.590, respectively.

This result holds when sector dummies, a dummy for regional disparities, the share of highly qualified employees, a dummy variable representing enhancement of teamwork in the foregoing three years and a dummy variable indicating a change in the market or customer requirements in the foregoing three years, and variables controlling for firm characteristics such as size, age and export activity as well as the competitive situation (specification (2)) and product innovations (specification (3)) are considered.[14] However, the value of the marginal effects changes. Thus, an older staff is negatively related to the likelihood of introducing new or significantly improved technologies in the operating process, and hypothesis 1 is approved. This is partly in line with the finding of Schneider (2008) who finds an inverse u-shaped age innovation profile in the manufacturing sector. Furthermore, the results support the empirical evidence found by Rouvinen (2002) and Nishimura, Minetaki, Shirai, and Kurokawa (2004). They also find a negative influence of older employees on the process innovation probability and technological progress in the manufacturing industries. This result may be explained by different issues. Firstly, it may be that older workers have more problems to adopt to changes in the operating process, especially when they have had a longer tenure. This is supported by the "deficit-model" mentioned before and by the findings of Morris and Venkatesh (2000). This effect could be boosted by the kind of changes, especially caused by the challenges of new technologies and software that cause problems for older workers as stated by, e.g. de Koning and Gelderblom (2006) and Schleife (2006) or Borghans and ter Weel (2002), who find that employees older than 30 years have lower ICT skills. Secondly, older firms which mainly employ older workers with longer job tenure may be more traditional and therefore less inclined to innovate or to change the working routine at all.[15] Thirdly, workers

[14]Due to item non-response for the dummy variable representing service product innovation, the sample size is reduced to 259 observations. Estimations (1) and (2) were also done with this reduced sample. The results did not change qualitatively.

[15]This explanation, however, can be excluded, since the consideration of firm age in the estimation does not change the results.

younger than 30 years have a high productivity and a high potential in terms of mastering equipment and software (Tijdens and Steijn 2005). Moreover, the knowledge of this age group may still be up to date as their educational achievement is recent. The result on the negative relationship between the age groups and technology adoption might also be explained by cohort effects. However, age and cohort effects cannot be distinguished since the data are only cross-sectional and lack the time dimension.

Table 2.2: Average Marginal Effects of Probit Estimations, Age Groups

dependent variable: dummy for adoption of new technologies			
	(1)	(2)	(3)
share of empl. 30 - 40 years	-0.315*	-0.353*	-0.365*
	(0.178)	(0.199)	(0.195)
share of empl. 40 - 55 years	-0.381**	-0.451**	-0.485***
	(0.156)	(0.175)	(0.171)
share of empl. > 55 years	-0.590***	-0.801***	-0.732***
	(0.215)	(0.257)	(0.252)
share of highly qualified empl.		0.033	0.040
		(0.116)	(0.115)
firm size (log. employees)		-0.024	-0.027
		(0.026)	(0.025)
firm age		0.005*	0.006**
		(0.003)	(0.003)
enhancement of teamwork		0.123**	0.066
		(0.059)	(0.059)
change customer requirements		0.242***	0.202***
		(0.063)	(0.068)
exporter		-0.041	-0.042
		(0.065)	(0.064)
foreign competitors		0.044	0.021
		(0.063)	(0.062)
product innovation			0.315***
			(0.062)
East Germany		-0.016	0.021
		(0.076)	(0.072)
Sector Dummies		*	n.s.
number of observations	356	284	259
Pseudo R^2	0.02	0.14	0.24

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses. Reference categories: Share of employees younger than 30 years, share of medium qualified and unqualified employees.

The average marginal effect of the share of highly qualified employees is not statistically significant in both specifications. Thus, there seems to be no positive relationship between the share of highly qualified employees and the probability of technology adoption. This result is unexpected. The firms in each of the analysed sectors are quite homogeneous with regard to the qualification and skill level of the employees. Thus, the qualification might be intercepted by the sector dummies.

Firm size, proxied by the logarithm of the number of employees, has no significant impact on the probability of technology adoption in both specifications. The firms contained in this sample have at the most 250 employees. Thus, the range of firm size might be too small to cover real size effects on the probability of technology adoption. Literature finding a psoitive relationship between firm size and ICT diffusion uses data containing more larger firms and fewer smaller firms (e.g. Hollenstein and Wörter 2004, Battisti, Hollenstein, Stoneman, and Wörter 2007).

The relationship between firm age and technology adoption is positive in specification (2) and (3). The marginal effect is 0.005 and 0.006, respectively. Thus, firms that are older are more likely to adopt new technologies compared to younger firms. This result suggests that it is rather the experience a firm has in changing processes and adopting new technologies that counts.

The enhancement of teamwork in the last three years is positively related to the probability of adopting new technologies in specification (2). This is in line with the empirical literature that finds a positive relationship between innovative workplace practices like teamwork and ICT or computer adoption (Hollenstein and Wörter 2004, Borghans and ter Weel 2006, Battisti, Hollenstein, Stoneman, and Wörter 2007). However, the dummy representing enhancement of teamwork turns insignificant when taking product innovations into account (specification (3)). This suggests that in general innovative firms also tend to be innovative regarding their workplace organisation. Considering the results of the bivariate Probit model confirms that there is only a complementary relationship between technology adoption and enhancement of teamwork if product innovations are not taken into account (see Table 2.7 in the appendix.) The results with regard to the age groups do not differ from the results of the univariate Probit, shown in Table 2.6 in the appendix. The coefficient estimates of the bivariate Probit, however, reveal that the share of employees between 30 and 40 years, compared to the share of employees younger than 30 years, is negatively related to the probability of teamwork enhancement. This is contradictory to the literature finding a negative relationship between innovative workplace practices and employees being older than 50 years (e.g. Beckmann 2001, Beckmann 2007, Aubert, Caroli, and Roger 2006). A possible explanation could be that the employees between 30 and 40 years, belonging to the group of the so called prime-age workers who exhibit the highest productivity, mainly hold leadership positions with decision authority. This authority and responsibility would possibly be reduced or distributed in a team. Consequently, this age group might not fully unfold its potential when working in a team.

The variable for change in the customer requirements in the foregoing three years shows the expected sign and is statistically significant in both specifications. This confirms the dependence of service firms, particularly small and medium-sized, on their customers and the importance of the close interaction between these firms and their clients.

Exporting activities are not correlated to the probability of technology adoption in specification (2) and (3). Thus, exporting service firms seem not to depend more on latest technologies than non-exporting service firms. Although it is still costly to adopt new technologies, the costs of adopting new and more advanced technologies and software have decreased in the last few years. Consequently, it might not pay off to implement technologies and software only for exporting activities, but for the entire firm since there is also savings and efficiency capacity through technologies in office-to-office communication.

The marginal effect of the variable representing the existence of foreign competitors is not significant in both specifications. The existence of foreign competitors might be a weak proxy for the competitive situation in general. This proxy might not be able to cover for the types of competition that matter for the probability of technology adoption (e.g. Borghans and ter Weel 2006).

The regional dummy representing potential differences between East and West Germany is statistically not significant. Although there are still differences between the productivity of East and West German firms, this does not touch their probability of technology adoption.

The sector dummies are jointly significant at the ten percent level in specification (2). However, taking product innovations into account disposes of this significance (specification (3)). This suggests that the nine sectors belonging to the service providers of the information society are rather homogeneous regarding their technology adoption behaviour, in particular, if the technology adoption is related to a product innovation.

Service product innovations are highly and positively correlated with the probability of technology adoption (see last row of Table 2.2). This might be due to the interplay between product and process innovation, considering the adoption of new technology and software as an example for process innovation.

Table 2.3 shows the average marginal effects of the Probit estimations of the age dispersion within the workforce measured by the weighted Herfindahl index[16] and the coefficients of the Linear Probability Model estimations taking into account an interaction term between the weighted Herfinfahl index and teamwork. Specifications (5) and (6) equal specifications (2) and (3) of Table 2.2, except that instead of the age groups the weighted Herfindahl index is included. Specification (4) shows the raw effect of the employees' age distribution represented by the weighted Herfindahl index. The average marginal effect of the weighted Herfindahl index is not statistically significant in specification (5). When taking product innovations into account (specification (6)), the average marginal effect of the weighted Herfindahl index turns to be negative at the ten percent level.[17] A negative sign of the marginal effect of the weighted Herfindahl index means that a more dispersed age of the workforce is positively related to the adoption of new technologies. The coefficient, however, is still statistically insignificant in specification (6) (see Table 2.8 in the appendix). Hence, one can not maintain a

[16]The coefficients of the Probit estimations are shown in Table 2.8 in the appendix.

[17]All estimations have also been run with the reduced sample of 259 observations. The results did not change qualitatively.

relationship between technology adoption and the weighted Herfindahl index since the statistical evidence is weak. That indicates that the age structure of the workforce in terms of age dispersion is not related to the probability of technology adoption, and hypothesis 2 cannot be approved. Except from firm age, the variables and controls contained in the estimations do not differ to a significant extent from those in Table 2.2.

Table 2.9 in the appendix shows the estimates of the bivariate Probit model. The likelihood-ratio test again reveals only a complementary relationship between technology adoption and enhancement of teamwork if product innovations are not considered. There is no significant relationship between the age dispersion of the employees, represented by the weighted Herfindahl index, and the enhancement of teamwork. The coefficient estimates of the weighted Herfindahl index and the covariates on the probability of technology adoption do not change compared to the univariate Probit.

The results of the Linear Probability Model estimation are depicted in the last column of Table 2.3.[18] The variable representing the weighted Herfindahl index is significant and has a negative sign. An interaction term between the weighted Herfindahl index and enhancement of teamwork is included. This interaction term is positive and significant. This indicates that in firms which make intense use of teamwork a low dispersion of the employees' age is positively related to the probability of technology adoption. The effect is about 0.113. However, hypothesis 3 cannot be approved, although age-mixed teams are found to be successful with regard to productivity in the literature. The results found here might be due to the interaction term between teamwork and workforce's age dispersion, represented by the weighted Herfindahl index, which is not a good proxy for age-mixed teams.

[18]The method proposed by Ai and Norton (2003) and permuted by Norton, Wang, and Ai (2004) was also used to analyse the effect of the interaction between the weighted Herfindahl index and the dummy variable of teamwork in the Probit model. The results did not change and are available on request. The Linear Probability Model predicts seven values outside the 0-1 range of the probability of technology adoption. This is less than five percent and thus another promotion for the use of the Linear Probability Model instead of the Probit to analyse the interactions.

Table 2.3: Average Marginal Effects of Probit Estimations and Coefficients of Linear Probability Model Estimations, Herfindahl index

dependent variable: dummy for adoption of new technologies				
		Probit		LPM
	(4)	(5)	(6)	(7)
weighted Herfindahl index	-0.122	-0.231	-0.394*	-0.689**
	(0.202)	(0.244)	(0.238)	(0.304)
share of highly qualified empl.		0.005	0.027	0.034
		(0.116)	(0.115)	(0.121)
firm size (log. employees)		-0.012	-0.026	-0.028
		(0.028)	(0.027)	(0.028)
firm age		0.004	0.005**	0.006**
		(0.003)	(0.003)	(0.003)
enhancement of teamwork		0.126**	0.068	-0.248
		(0.061)	(0.060)	(0.197)
change customer requirements		0.252***	0.205***	0.197***
		(0.064)	(0.069)	(0.067)
exporter		-0.021	-0.020	-0.038
		(0.066)	(0.066)	(0.068)
foreign competitors		0.054	0.022	0.015
		(0.064)	(0.063)	(0.065)
product innovation			0.336***	0.339***
			(0.063)	(0.062)
teamwork*weighted Herfindahl				0.802*
				(0.471)
East Germany		-0.037	-0.015	-0.007
		(0.077)	(0.074)	(0.077)
Sector Dummies		n.s.	n.s.	n.s.
number of observations	356	284	259	259
Pseudo R^2	0.00	0.11	0.21	
adjusted R^2				0.21

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses.
Reference categories: share of medium qualified and unqualified employees.

2.5 Conclusion

Using a cross-sectional data set of 356 small and medium-sized firms of the German ICT and knowledge-intensive service sectors in the year 2005, this paper provides empirical evidence on the relationship between the age structure of the workforce and the probability of adopting new or significantly improved technologies. Firms with a higher share of younger employees are more likely to adopt new technologies than firms with an older workforce. Furthermore, the older the workforce the less likely firms are to adopt new technologies. Compared to employees being younger than 30 years an older workforce is negatively related to the probability of adopting new technologies in small and medium-sized service firms. This holds for employees between 30 and 40 years, 40 and 55 years and older than 55 years. The age of the workforce seems to be negatively related to the probability of technology or software adoption.

However, the dispersion of the employees' age within the workforce does not seem to do so. The concentration of the employees' age, measured by a weighted Herfindahl index, has only a weak and not robust relation to the probability of technology adoption. This does not hold for firms that intensified teamwork, however. In these firms, employees of the same age are positively related to the probability of adopting new technologies. As technology adoption is a key factor in order to stay competitive, these results suggest that firms with a homogenous workforce in terms of age should intensify teamwork in their workplace organisation.

Finally, the analyses show that there are further factors affecting the adoption of new technologies: the firm age, to a certain extent the enhancement of teamwork, the introduction of product innovations and the change of market and customer requirements are positively related to the probability of technology adoption. Especially the relationships between technology adoption and changed market or customer requirements as well as between product innovation seem to be very robust. As the analysed firms belong to the ICT and knowledge-intensive service sectors and are mainly small and medium-sized they depend to a great extent on the interaction with their clients and customers and on a close cooperation with them. Thus, new or changed requirements will lead to new or improved services, that is product innovation. These new or improved services, however, might require the use of new technologies or software. Changed customer requirements could also imply a new or different way of the service provision and thus require the adoption of new technologies or software to meet these demands. Further research on technology adoption in service sector firms and especially in the ICT and knowledge-intensive service sectors should therefore focus on this relation. The impact, its extent and the different facets of product innovation as well as the customers and their interaction should be analysed to learn more about the determinants of technology adoption.

This becomes all the more important given that the skills of the employees and the external environment of the firm in terms of competition and exporting activity do not seem to matter.

2.6 Appendix

The ZEW quarterly business survey among service providers of the information society includes the following industries (codes of the German Classification of Economic Activities, Edition 2003 in parentheses): software and IT services (71.33.0, 72.10.0-72.60.2), ICT-specialised trade (51.43.1, 51.43.3-3.4, 51.84.0, 52.45.2, 52.49.5-9.6), telecommunication services (64.30.1-0.4), tax consultancy and accounting (74.12.1-2.5), management consultancy (74.11.1-1.5, 74.13.1-3.2, 74.14.1-4.2), architecture (74.20.1-0.5), technical consultancy and planning (74.20.5-0.9), research and development (73.10.1-73.20.2) and advertising (74.40.1-0.2). Table 2.4 shows how the industries are distributed in the sample.

Table 2.4: Distribution of Firms Across Industries in the Sample

Industry	**Observations**	**Percentage**
software and IT services	34	9.55
ICT-specialised trade	61	17.13
telecommunication services	14	3.93
tax consultancy and accounting	61	17.13
management consultancy	30	8.43
architecture	49	13.76
technical consultancy and planning	42	11.80
research and development	43	12.08
advertising	22	6.18
sum	356	100

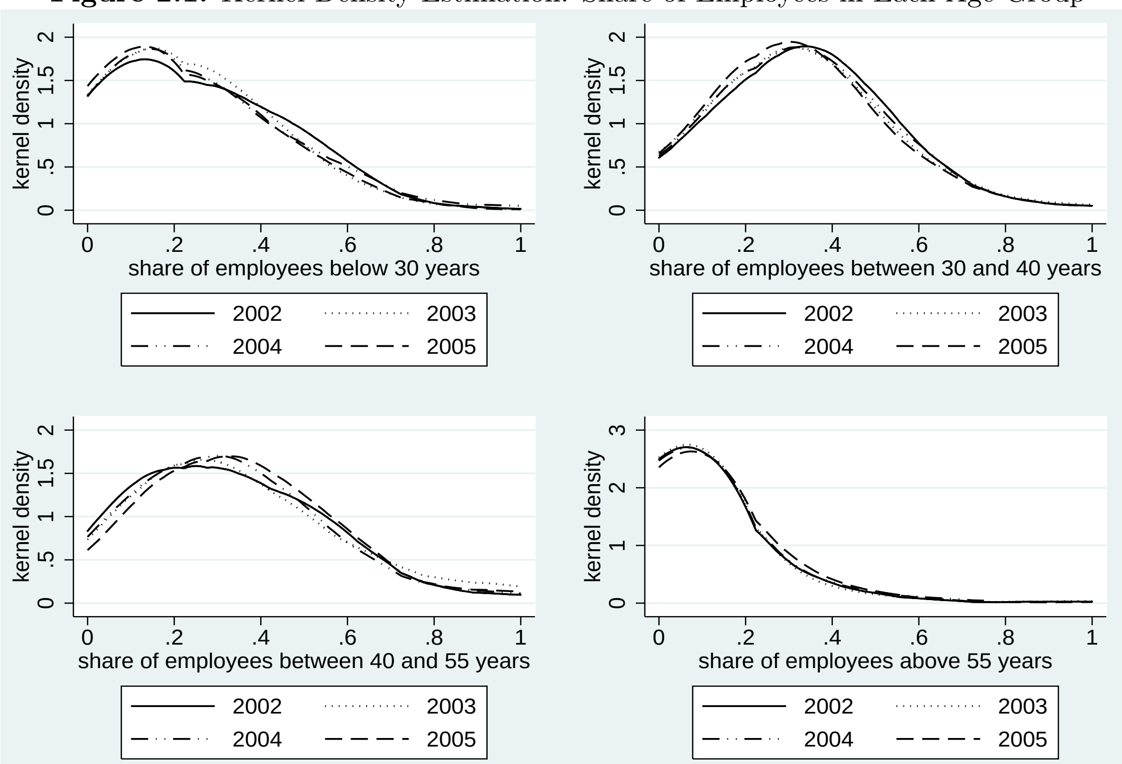
Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

Table 2.5: Development of Percentage Shares of Age Groups

Year	Variable	Obs	Mean	Std. Dev.	Min.	Max.
2002	share of empl. < 30 years	391	0.240	0.201	0	1
	share of empl. 30 - 40 years	391	0.333	0.197	0	1
	share of empl. 40 - 55 years	391	0.327	0.225	0	1
	share of empl. > 55 years	391	0.100	0.147	0	1
2003	share of empl. < 30 years	437	0.224	0.187	0	1
	share of empl. 30 - 40 years	437	0.322	0.204	0	1
	share of empl. 40 - 55 years	437	0.354	0.248	0	1
	share of empl. > 55 years	437	0.100	0.151	0	1
2004	share of empl. < 30 years	406	0.243	0.213	0	1
	share of empl. 30 - 40 years	406	0.328	0.199	0	1
	share of empl. 40 - 55 years	406	0.329	0.225	0	1
	share of empl. > 55 years	406	0.101	0.136	0	0.75
2005	share of empl. < 30 years	362	0.216	0.192	0	1
	share of empl. 30 - 40 years	362	0.317	0.195	0	1
	share of empl. 40 - 55 years	362	0.355	0.224	0	1
	share of empl. > 55 years	362	0.112	0.145	0	1

Source: ZEW Quarterly business survey among service providers of the information society, 2002, 2003, 2004, 2005 (in each case 3rd quarter), own calculations.

Figure 2.1: Kernel Density Estimation: Share of Employees in Each Age Group



Source: ZEW Quarterly business survey among service providers of the information society, 2002, 2003, 2004, 2005 (in each case 3rd quarter); in each case bandwith=0.1

Table 2.6: Coefficients of Probit Estimations, Age Groups

dependent variable: dummy for adoption of new technologies			
	(1)	(2)	(3)
share of empl. 30 - 40 years	-0.808*	-1.048*	-1.226*
	(0.463)	(0.599)	(0.666)
share of empl. 40 - 55 years	-0.979**	-1.337**	-1.628***
	(0.410)	(0.536)	(0.597)
share of empl. > 55 years	-1.515***	-2.376***	-2.457***
	(0.569)	(0.799)	(0.883)
share of highly qualified empl.		0.099	0.135
		(0.345)	(0.388)
firm size (log. employees)		-0.071	-0.089
		(0.078)	(0.085)
firm age		0.015*	0.021**
		(0.008)	(0.008)
enhancement of teamwork		0.358**	0.219
		(0.173)	(0.192)
change customer requirements		0.694***	0.641***
		(0.186)	(0.215)
exporter		-0.122	-0.142
		(0.193)	(0.216)
foreign competitors		0.129	0.070
		(0.183)	(0.205)
product innovation			0.950***
			(0.191)
East Germany		-0.047	0.070
		(0.223)	(0.245)
Sector Dummies		*	n.s.
number of observations	356	284	259
Pseudo R^2	0.02	0.14	0.24

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses. Reference categories: Share of employees younger than 30 years, share of medium qualified and unqualified employees.

Table 2.7: Coefficients of Bivariate Probit Estimations, Age Groups

	dependent variable:			
	technology adoption	teamwork	technology adoption	teamwork
	(2)		(3)	
share of empl. 30 - 40 years	-1.221**	-1.539**	-1.345**	-1.715***
	(0.593)	(0.600)	(0.659)	(0.631)
share of empl. 40 - 55 years	-1.422***	-0.815	-1.681***	-0.790
	(0.532)	(0.526)	(0.594)	(0.545)
share of empl. > 55 years	-2.319***	0.195	-2.437***	0.068
	(0.794)	(0.758)	(0.880)	(0.883)
share of highly qualified empl.	0.066	-0.215	0.118	-0.158
	(0.343)	(0.343)	(0.387)	(0.367)
firm size (log. employees)	-0.050	0.171**	-0.077	-0.163**
	(0.077)	(0.079)	(0.084)	(0.082)
firm age	0.016**	0.005	0.021**	0.005
	(0.008)	(0.008)	(0.008)	(0.008)
change customer requirements	0.776***	0.761***	0.690***	0.717***
	(0.181)	(0.186)	(0.210)	(0.205)
exporter	-0.120	0.015	-0.133	-0.107
	(0.191)	(0.191)	(0.215)	(0.203)
foreign competitors	0.147	0.163	0.077	0.097
	(0.183)	(0.183)	(0.205)	(0.194)
product innovation			0.974***	0.376**
			(0.189)	(0.183)
East Germany	-0.031	0.101	0.076	0.060
	(0.222)	(0.221)	(0.244)	(0.231)
Sector Dummies	n.s.	n.s.	n.s.	n.s.
ρ	0.230		0.150	
	(0.106)		0.116	
Likelihood-ratio test of $\rho = 0$	χ^2 (1)=4.7897		χ^2 (1)=1.68074	
	Prob > χ^2=0.0286		Prob > χ^2=0.1948	
number of observations	284		259	
Wald χ^2 (36)	82.09			
Wald χ^2 (38)			103.81	

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses. Reference categories: Share of employees younger than 30 years, share of medium qualified and unqualified employees.

Table 2.8: Coefficients of Probit Estimations, Herfindahl index

dependent variable: dummy for adoption of new technologies			
	(1)	(2)	(3)
weighted Herfindahl index	-0.307	-0.661	-1.277
	(0.507)	(0.701)	(0.871)
share of highly qualified empl.		0.014	0.087
		(0.116)	(0.374)
firm size (log. employees)		-0.035	-0.083
		(0.080)	(0.088)
firm age		0.011	0.016*
		(0.008)	(0.008)
enhancement of teamwork		0.353**	0.215
		(0.169)	(0.187)
change customer requirements		0.694***	0.626***
		(0.182)	(0.210)
exporter		-0.061	-0.066
		(0.189)	(0.213)
foreign competitors		0.155	0.070
		(0.180)	(0.202)
product innovation			0.976***
			(0.189)
East Germany		-0.106	-0.050
		(0.218)	(0.240)
Sector Dummies		n.s.	n.s.
number of observations	356	284	259
Pseudo R^2	0.00	0.11	0.21

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses. Reference categories: share of medium qualified and unqualified employees.

Table 2.9: Coefficients of Bivariate Probit Estimations, Herfindahl index

	dependent variable:			
	technology adoption	teamwork	technology adoption	teamwork
	(2)		(3)	
weighted Herfindahl index	-0.743	-0.791	-1.348*	-1.115
	(0.697)	(0.727)	(0.777)	(0.763)
share of highly qualified empl.	-0.041	-0.414	0.058	-0.364
	(0.329)	(0.333)	(0.373)	(0.356)
firm size (log. employees)	-0.019	0.129	-0.075	-0.102
	(0.079)	(0.081)	(0.088)	(0.085)
firm age	0.011	0.005	0.016**	0.005
	(0.008)	(0.008)	(0.008)	(0.008)
change customer requirements	0.774***	0.740***	0.671***	0.669***
	(0.177)	(0.183)	(0.202)	(0.202)
exporter	-0.061	0.007	-0.058	0.111
	(0.188)	(0.188)	(0.212)	(0.201)
foreign competitors	0.172	0.156	0.077	0.083
	(0.179)	(0.179)	(0.201)	(0.191)
product innovation			1.001***	0.397**
			(0.187)	(0.182)
East Germany	-0.092	0.081	-0.048	0.013
	(0.217)	(0.219)	(0.239)	(0.230)
Sector Dummies	n.s.	n.s.	n.s.	n.s.
ρ	0.226		0.142	
	(0.104)		0.114	
Likelihood-ratio test of $\rho = 0$	χ^2 (1)=4.7914		χ^2 (1)=1.5662	
	Prob > χ^2=0.0286		Prob > χ^2=0.2108	
number of observations	284		259	
Wald χ^2 (32)	68.32			
Wald χ^2 (34)			103.81	

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses.
Reference categories: Share of medium qualified and unqualified employees.

3 Do Older Workers Lower IT-Enabled Productivity?*

3.1 Introduction

According to the Lisbon Agenda, the strategic goal for the European Union is "...to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion" (Lisbon European Council 2000). As general purpose technologies (Bresnahan and Trajtenberg 1995) information and communication technologies (ICT) have been recognised as a key technology for competitiveness. They have diffused to firms and workplaces of all sectors during the last decades giving rise to the so-called knowledge-based economy. About 58 percent of the employees in Germany currently use a computer at their workplace on a regular basis compared to 46 percent in 2002 (Statistisches Bundesamt 2007a). Various empirical evidence shows that the use of ICT enhances firm productivity, in particular if ICT usage is complemented by appropriate organisational measures.[1] A look at the country level, however, reveals that the contribution of ICT capital to GDP growth, although still positive, has diminished considerably during the period between 2000 and 2005 compared to the period between 1995 and 2000 in almost all OECD countries.[2]

A further major trend in industrialised countries is marked by an increase in life expectancy and a simultaneous decrease in birthrates, leading to an enormous

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[1] A recent survey of the literature is given by Draca, Sadun, and van Reenen (2007).

[2] See the OECD productivity data base, 2006.

pressure on the social security systems. The target set up by the Stockholm Council in March 2001 is to raise the employment rate of seniors in the European Union (i.e. people aged 55 to 64 years) to 50% by 2010. In the EU-25, the labour force participation of older people has increased by 5.9 percentage points from 2000 to 2005, reaching a level of 42.5%. In Germany, this increase was above average with 7.5 percentage points and a level of 44.9% in 2005 (Aliaga and Romans 2006).[3] This development represents a great challenge for firms. High productivity is an important objective in order to stay competitive in an economy that is characterised by rapid technological progress. Does an ageing workforce conflict with this objective?

This paper provides empirical evidence on the question whether firms' IT-enabled labour productivity is affected by the age structure of the workforce. Therefore, we apply a production function approach with heterogenous labour to a firm-level data set from the German manufacturing and services industries. It comprises data from 1039 firms observed in the years 2004 and 2007.

We find that employees aged younger than 30 years are significantly less productive than prime age employees, whereas employees being older than 49 do not differ significantly from prime age employees between 30 and 49. Older computer users are significantly more productive than older non-computer users. The significantly positive relationship between labour productivity and IT intensity is not affected by the proportion of older employees implying that older employees do not lower IT-enabled productivity.

The paper is structured as follows: The next section gives an overview about the background discussion in economic literature. Section three presents some theoretical considerations and the empirical model. The data used for the empirical analyses is presented and described in section four. In section five the results are presented and discussed. Section six concludes.

[3]Several countries of the European Union have already passed the goal of 50%. In Sweden, for example, nearly 70% of the people aged between 55 and 64 years participated in the labour market in the year 2005 and in Denmark the average labour force participation rate of this age group was about 60% in 2005 (see Aliaga and Romans, 2006).

3.2 Background Discussion

The topic of this paper is related to various strands of the literature. First, there is the literature about the productivity effects of ICT. Recent firm-level studies all find a positive and significant relationship between productivity and ICT with ICT being generally measured by ICT capital or ICT investment.[4] Moreover, these studies claim that ICT has to be accompanied by appropriate organisational measures in order to fully exploit the productivity gains. Therefore, ICT investment and organisational investment are interpreted as strategic complements.[5]

A further strand of literature deals with the so-called age-biased technological change. It analyses whether older workers have age-related disadvantages in using new technologies compared to younger workers. Some studies focus on the relationship between the use of ICT and the employment of elderly persons at the firm level.[6]

As Bartel and Sichermann (1993) point out, technological change impacts the retirement decision of older workers in two different ways: On the one hand, it directly affects retirement decisions by enforcing training and thus gives incentives to stay on the job. On the other hand, technological change - when it arises unexpectedly - accelerates the depreciation of human capital and thus makes training less attractive in particular for older employees, who then may prefer to retire earlier (Bartel and Sichermann 1993). The empirical study by Friedberg (2003) points in the same direction. Using two data sets from the U.S. she finds that computer users tend to retire later than non-users because they probably have comparative advantages and are ready to invest in training. However, the readiness to invest in training is negatively correlated with impeding retirement.

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[4] See for instance the overviews by Bertschek (2003), Brynjolfsson and Hitt (2000) and Draca, Sadun, and van Reenen (2007).

[5] This discussion is mainly related to decentralising organisational measures implying a greater involvement of employees in decision-making processes and more responsibilities of employees. Some examples are team work, flat hierarchies, autonomous working groups or incentive pay. See for instance Black and Lynch (2001), Brynjolfsson and Hitt (2000), Bresnahan, Brynjolfsson, and Hitt (2002), and Bertschek and Kaiser (2004).

[6] For empirical evidence for Germany, see for example Bertschek (2004) and Boockmann and Zwick (2004).

Taking into account more detailed information on employees' individual characteristics reveals that it is not the age that is decisive for the use or non-use of ICT, it is rather occupation, education and skills that determine the use of ICT (Borghans and ter Weel 2002, Friedberg 2003, Hirsch, MacPherson, and Hardy 2000, Schleife 2006, Weinberg 2004). The use of new technologies generally increases skill requirements - a topic which is extensively discussed in the skill-biased technological change literature.[7]

Taking into account the complementary relationship between ICT and organisational factors, some empirical studies also consider workplace practices to explain the age structure of the workforce at the firm level (Aubert, Caroli, and Roger 2006, Beckmann 2001, Bertschek 2004). They find that innovative workplace practices giving more decision-making authority and responsibility to employees is negatively related to the employment of older workers.

The third and last strand of literature which is relevant to our paper deals with the productivity of older workers. From a gerontological point of view, the fluid part of the brainpower — the part which is responsible for efficiently processing information and for adapting to new situations — decreases with age. By contrast, the cristalline intelligence comprising verbal competence and experience rather increases with age. As Börsch-Supan, Düzgün, and Weiss (2006) point out, it is not only the individual productivity that matters. The working environment of employees such as the age structure of a team, the workplace organisation and the spread of lifelong learning opportunities are more important.

There are many economic and empirical studies on the relationship between age and productivity (see the surveys by Börsch-Supan, Düzgün, and Weiss, 2005, and by Skirbekk, 2004). Firm-level studies usually measure firm-level productivity by sales or by the value added per employee. Studies at the individual level focus on wages as an individual measure of productivity. Analyses based on linked employer-employee data combine the two approaches. Most econometric studies find a hump shaped age-productivity profile implying a relatively high productivity

[7] See for example the overview articles by Chennells and van Reenen (2002) and Card and DiNardo (2002). For an analysis of changing skill requirements owing to the diffusion of IT see Autor, Levy, and Murnane (2003) and Spitz-Oener (2006).

for prime age workers (aged between 30 and 50 or between 35 and 55) and lower productivities for younger and older workers.[8] Some authors highlight the importance of employees' formal qualification (Haltiwanger, Lane, and Spletzer,1999, Hellerstein, Neumark, and Troske, 1999, Crépon, Deniau, and Pérez-Duarte, 2002) as well as the importance of experience aquired in the firm (Ilmakunnas, Maliranta, and Vainiomäki 2004).

To the best of our knowledge, there is no study which relates firm productivity to the use of ICT *and* to the age structure of employees. On the one hand, the productivity studies that focus on the effects of the age structure of employees do not consider ICT as a further production factor. On the other hand, studies that find empirical evidence for positive productivity effects of ICT at the firm level do not consider the age structure of the workforce. Our paper attempts to close this gap by considering both ICT and the age structure of the workforce using two waves of a firm-level data set.

3.3 Analytical Framework

The basis of our simplified analytical framework is a Cobb-Douglas production function with various input factors:

$$Y_i = f(A_i,\ L_i^*,\ K_i, WO_i, controls). \tag{3.1}$$

[8] To cite some examples, Crépon, Deniau, and Pérez-Duarte (2002) use French linked employer-employee data and find the highest productivity for prime age workers who are aged between 25 and 34 years old. Haltiwanger, Lane, and Spletzer (1999) provide evidence using a U.S. longitudinal linked employer-employee data set. They find a lower productivity of employees older than 55. The age group between 30 and 49 turns out to be the most productive. However, the age structure of the workforce does not play a role for changes in productivity over time. For the case of Germany Schneider (2007), using linked employer-employee data, also finds a hump shaped age-productivity profile. There is evidence for Denmark (Grund and Westergard-Nielsen 2008), Finland (Ilmakunnas, Maliranta, and Vainiomäki 2004), Sweden (Prskawetz, Mahlberg, Skirbekk, Freund, Winkler-Dworak, Lindh, Malmberg, Jans, Nordström, and Andersson 2006), as well as further evidence for France (Aubert and Crépon 2003) and the U.S. (Hellerstein, Neumark, and Troske 1999).

The output Y_i of firm i depends on the input factors labour, L_i^*, capital, K_i and workplace organisation WO_i. The parameter A_i measures total factor productivity and reflects the efficiency of production. Controls comprise industry, region and firms' export activity.

The labour parameter L_i^* represents the aggregated efficiency units of labour. It consists of k different types L_i^k of employees working with different productivities:

$$L_i^* = g(L_i^{qual},\ L_i^{age}, L_i^{PC}) \tag{3.2}$$

where L_i^{qual} represents labour heterogeneity according to qualification, L_i^{age} represents the age structure of employees, and L_i^{PC} takes into account the share of employees working on a computer.[9]

More formal versions of this framework and a discussion of the underlying assumptions can be found in Hellerstein, Neumark, and Troske (1999), Crépon, Deniau, and Pérez-Duarte (2002) and Schneider (2007).

In the econometric estimations labour productivity measured by the logarithm of sales per employee is used as dependent variable:

$$ln\left(\frac{Y_i}{L_i}\right) \quad = \quad f(lnA_i, lnL_i, lnK_i, L_i^{qual},\ L_i^{age}, L_i^{PC}, WO_i, controls)$$

As input factors we consider labour, capital, the workforce's qualification and age structure, employees working on computers and workplace organisation. We expect that labour productivity is positively related to high- and medium-skilled employees, to employees working at computers and to high performance workplace practices. Younger and older employees are expected to be less productive than the reference group of prime age employees. According to previous research results presented in the background discussions, we also hypothesise that there are complementarities

[9] Instead of interpreting the share of employees using computers at the workplace as a factor of labour heterogeneity, it might alternatively be interpreted as a measure of IT capital.

between IT intensity and workplace organisation. Additionally, we expect that older employees negatively interact with IT intensity and workplace organisation. The following section describes the measures of the variables as used in the estimations.

3.4 Data Description

The firm-level data used for the empirical analyses result from the ICT survey of the Centre for European Economic Research (ZEW) and was collected in 2004 and 2007. Each year 4.400 firms were surveyed. The data are stratified according to industries (seven branches of the manufacturing industry and seven selected service sectors), to three size classes and to two regions (East/West Germany). The data are constructed as a panel, therefore the waves of 2004 and 2007 are merged in order to use information that is only contained in the wave of 2004.[10] Considering item non-response for the age variables, there remains a sample of 1039 firms.

Labour productivity is measured as the log of (total annual sales)/(total no. of employees) and is used as the output variable. The input factor labour is measured by the logarithmised number of employees, which represents at the same time firm size. Capital stock is approximated by the log of gross investment.[11]

The following variables take account of the heterogeneity of labour as put forward by the theoretical considerations:

QUALIFICATION: The qualification of the employees is presented by the proportion of employees being high-skilled (degree from university, university of

[10]Due to the fact that not all variables are contained in both waves, panel estimations cannot be provided.

[11]Capital stock could potentially be approximated by applying the perpetual inventory method. However, there are not enough waves available for this purpose. Moreover, there is no information about value added and material input. The latter might be particularly important for manufacturing firms. These measurement problems might bias the estimates of the corresponding parameters. Nevertheless, it is not unusual to use gross investment as a proxy for capital and to use sales and not value added as a performance measure, see for example Griffith, Huergo, Mairesse, and Peters (2006).

applied sciences or university of cooperative education) and medium-skilled (master craftsman, engineer or vocational training), respectively. The reference category is the proportion of low-skilled workers (without formal qualification).

AGE: The share of workers aged 50 or older and the share of workers aged younger than 30 reflect the age structure of the workforce. So-called prime age workers between 30 and 49 are the reference group.

PCWORK: The share of workers predominately working at a PC measures the workers' technological skills and at the same time it reflects the companies' IT intensity.

OLD PCWORK: The share of older workers (older than 49) predominately working at a PC.

WORKPLACE ORGANISATION: The dummy variables incentive wages and teams with profit and loss responsibility are measures of workplace organisation.

CONTROLS: A dummy variable accounts for firms' exporting activities. A dummy for East Germany takes account of the fact that East German firms are generally less productive than West German firms. Sector dummies control for sector-specific variation in labour productivity.[12]

The variables measuring workplace organisation, old pcwork, and the dummy variable accounting for export activity refer to the survey of 2004, all other variables are taken from the survey of 2007. Table 3.1 shows some descriptive statistics of the variables for the total sample if observations with item non-response for all used variables are dropped.

Table 3.1 reveals that the labour productivity is 158,594 Euro per employee on average. The average firm size in the sample is about 138 employees. On average,

[12] The distribution of firms across sectors can be found in Table 3.4 in the appendix.

Table 3.1: Descriptive Statistics: Total Sample

Variable	Mean	Std. Dev.	Min.	Max.
labour productivity	158594	131779	5147	800000
firm size (no of employees)	138	301	5	4100
gross investment	1402506	3773259	1000	40000000
share of employees $<$ 30 years	0.252	0.172	0	0.9
share of employees $>$ 49 years	0.212	0.147	0	0.9
share of high-skilled employees	0.216	0.248	0	1
share of medium-skilled employees	0.593	0.252	0	1
pcwork	0.484	0.336	0	1
old pcwork	0.321	0.381	0	1
incentive wages	0.555	0.497	0	1
units with P&L responsibility	0.36	0.48	0	1
exporting activities	0.528	0.5	0	1
N		776		

Source: ZEW ICT survey 2004 & 2007, own calculations.

the firms of the sample have a gross investment of about 1.4 million Euros. The share of employees being younger than 30 years is about 25 percent, whereas the share of employees aged 50 years or older is about 21 percent. The major share of employees is medium-skilled (about 59 percent). On average, 22 percent of the employees of the firms in the sample are high-skilled. About half of the staff works predominantly at a computer, whereas this share is lower amongst the older employees. On average, 32 percent of the employees being 50 years or older are working mainly at a computer. As for human resource practices, more than half of the firms use incentive wages, whereas only about 36 percent of the firms in the sample have units with profit and loss responsibility.

3.5 Empirical Results

The results of the OLS estimations are depicted in Tables 3.2 and 3.3. Specification (1) shows the raw effects of the age groups. It implies that workers younger than 30 and workers older than 49 are less productive than prime age workers - a result that corresponds to the theoretical considerations. This result changes when sector dummies and a dummy for regional disparities are introduced (specification (2)). In this case, the share of older workers becomes insignificant whereas the coefficient of younger workers remains negatively significant.

Specification (3) additionally contains the input factors as well as further control variables. The input factors show the expected signs and coefficients.[13]

Table 3.2: Coefficients of OLS Estimation

dependent variable: log labour productivity				
	(1)	(2)	(3)	(4)
share of employees < 30 years	-0.259*	-0.256**	-0.379***	-0.376***
	(0.138)	(0.128)	(0.123)	(0.126)
share of employees > 49 years	-0.352**	-0.259	-0.075	-0.184
	(0.175)	(0.168)	(0.163)	(0.165)
log (employment)			-0.105***	-0.118***
			(0.025)	(0.025)
log (gross investment)			0.133***	0.144***
			(0.019)	(0.019)
share of high-skilled employees			0.501***	0.408**
			(0.162)	(0.163)
share of medium-skilled employees			0.354***	0.275**
			(0.118)	(0.118)
pcwork			0.451***	0.436***
			(0.101)	(0.101)
incentive wages			0.124***	0.118***
			(0.045)	(0.045)
units with P&L responsibility			0.108**	0.094*
			(0.049)	(0.050)
exporting activities			0.101**	0.087*
			(0.047)	(0.047)
old pcwork				0.124**
				(0.062)
dummies for sectors and region	no	yes	yes	yes
Number of observations	1039	1039	808	776
R^2	0.006	0.184	0.365	0.375
F statistic	3.15	19.37	20.58	20.73

Significance levels : $*$: 10% $**$: 5% $***$: 1%. Heteroscedasticity-robust standard errors in parentheses. Reference categories: share of employees between 30 and 49 years, share of low-skilled employees.

[13] The coefficient of labour is negative since it reflects the production elasticity of labour minus one. The estimated coefficients of the various categories of labour plus one reflect the productivity of the respective labour category relative to its reference group. For example, the relative productivity of employees working on computers according to specification (3) in Table 3.2 is $0.451 + 1$.

IT intensity measured by the proportion of employees working predominately at a computer is also positively significant reflecting the positive relationship between productivity and ICT that is also found in several other micro and macro studies. Moreover, high-skilled and medium-skilled employees are more productive than low-skilled employees. The human resource measures incentive wages and units with profit and loss responsibility are positively associated with labour productivity. Exporting firms are more productive than non-exporting firms.[14]

A further estimation considers the proportion of older employees working at a computer (specification (4) of Table 3.2). It has a positive and significant coefficient implying that older workers using a computer are more productive than older workers not using a computer. This result is in line with previous results from the skill-biased technological change literature showing that computer users are more productive than non-users, not because they use computers but because they are better qualified for using a computer.

Interaction effects between age groups and IT intensity are taken into account in specification (5) of Table 3.3. The estimated coefficient is negative in case of the interaction term between younger workers and IT usage whereas it is positive in case of the interaction between older workers and IT usage hinting at complementarities between experience and technology. However, both coefficients are insignificant. Thus, the positive and significant marginal effect of IT usage on firms' labour productivity is not affected by the percentage of older workers. The coefficient of the proportion of employees being younger than 30 years becomes insignificant.

As motivated in section 3.2, specifications (6) and (7) of Table 3.3 contain interaction terms between age groups and workplace practices and between IT intensity and workplace practices. However, these interaction terms are all insignificant. Moreover, the dummy variables presenting the use of units with own profit and loss responsibility turn to be insignificant as well.

[14]This is in line with several studies for instance by Bernard and Jensen (2004). These studies all find a positive relationship between productivity and exports.

Table 3.3: Coefficients of OLS Estimation with Interaction Terms

dependent variable: log labour productivity				
	(5)	(6)	(7)	(8)
share of employees < 30 years	-0.308	-0.375*	-0.381***	-0.281
	(0.200)	(0.192)	(0.123)	(0.244)
share of employees > 49 years	-0.195	-0.020	-0.077	-0.110
	(0.262)	(0.223)	(0.162)	(0.283)
log (employment)	-0.106***	-0.104***	-0.105***	-0.105***
	(0.025)	(0.025)	(0.025)	(0.025)
log (gross investment)	0.133***	0.133***	0.133***	0.133***
	(0.019)	(0.019)	(0.019)	(0.019)
share of high-skilled employees	0.507***	0.492***	0.500***	0.497***
	(0.162)	(0.163)	(0.163)	(0.165)
share of medium-skilled employees	0.351***	0.351***	0.354***	0.347***
	(0.117)	(0.118)	(0.118)	(0.118)
pcwork	0.425**	0.450***	0.443***	0.430**
	(0.171)	(0.100)	(0.133)	(0.206)
incentive wages	0.126***	0.192*	0.129*	0.201
	(0.044)	(0.107)	(0.072)	(0.128)
units with P&L responsibility	0.108**	0.065	0.084	0.038
	(0.049)	(0.118)	(0.082)	(0.153)
exporting activities	0.101**	0.100**	0.102**	0.101**
	(0.048)	(0.047)	(0.048)	(0.047)
below 30 years*pcwork	-0.143			-0.207
	(0.354)			(0.358)
above 49 years*pcwork	0.263			0.280
	(0.467)			(0.460)
incentive wages*pcwork			-0.012	-0.015
			(0.140)	(0.142)
units w. P&L responsibility*pcwork			0.049	0.047
			(0.153)	(0.163)
below 30 years*incentive wages		-0.124		-0.130
		(0.242)		(0.242)
above 49 years*incentive wages		-0.181		-0.171
		(0.339)		(0.340)
below 30 years*units with P&L responsibility		0.215		0.247
		(0.294)		(0.301)
above 49 years*units with P&L responsibility		-0.065		-0.081
		(0.426)		(0.439)
dummies for sectors and region	yes	yes	yes	yes
Number of observations	808	808	808	808
R^2	0.366	0.366	0.365	0.367
F statistic	18.98	17.57	19.14	15.43

Significance levels : $*$: 10% $**$: 5% $***$: 1%. Heteroscedasticity-robust standard errors in parentheses. Reference categories: share of employees between 30 and 49 years, share of low-skilled employees.

Finally, specification (8) of Table 3.3 combines specifications (5), (6) and (7). The results do not change significantly. The coefficient of the proportion of younger employees turns to be insignificant again, the interaction terms are all insignificant.[15]

To summarize the results: Employees aged younger than 30 are significantly less productive than prime age workers. The negative raw effect of older workers (50 or older) becomes insignificant when control variables are considered in the estimations. There are no significant interactions between the proportion of older workers and the IT intensity of the firm. Thus, older workers do not lower IT-enabled productivity. The percentage share of older employees working predominately at a computer reveals a positive and significant relationship with labour productivity. IT intensity is positively and significantly related to labour productivity. The same holds for the application of incentive wages and — in most of the specifications — for units with profit and loss responsibility. Interaction terms between these variables, however, are all insignificant. Thus, complementarities between the age structure of employees, incentive wages or units with profit and loss responsibility and IT intensity do not seem to exist.

One might suspect that the proportion of older workers in a company is positively selected and thus endogenous (see for instance Aubert and Crépon, 2003). On the one hand, companies might part with older workers for instance by early retirement programs. On the other hand, older employees might decide to leave the labour market if their workplaces are affected by technological change and if sufficient support by social security systems is available.

In order to account for that potential endogeneity problem, we firstly consider the development of the percentage shares of older and younger workers since 2001. Therefore, we use a third wave of our ICT survey conducted in 2002. As Table 3.5 in the appendix shows, the proportion of employees belonging to a certain age group varies only little over the considered time period on average. The proportion of employees being 50 years or older slightly increases from about 18 percent in

[15] The regressions presented in Table 3.3 were also run with old pcwork as the variable taking account of the share of older workers working predominately at a PC. However, the results did not change qualitatively.

2001 to about 22 percent in 2006. The proportion of employees aged younger than 30 years decreases from about 29 to about 26 percent. These developments seem to reflect the natural aging process of the workforce rather than a systematic selection mechanism. Moreover, the kernel density estimations in Figures 3.1 and 3.2 in the appendix as well as a Kolmogorov-Smirnov test indicate that the distributions of the proportion of younger as well as of older workers do not differ significantly over the three years 2002, 2004 and 2007.

Secondly, we use an instrumental variables approach estimated by two stage least squares. Two variables serve as instruments for the proportion of employees being older than 49 years: the firm age and the existence of a collective labour agreement. Firm age seems to be highly correlated with the proportion of older workers in a firm since a firm's workforce ages over a firm's life time. On the other hand, one may assume that the firms' productivity is rather related to organisational and technological factors that are important for efficient business processes than to firm age. The existence of a collective labour agreement reflects the fact that firms applying such an agreement are more restricted with respect to job protection than others and thus might be more inflexible with respect to dismissing older workers. The results can be found in Table 3.6 in the appendix. The two instruments are positive and significant. A test on overidentifying restrictions does not hint to an overidentification (Score Chi = 1.17489, p=0.2784). In the productivity estimation the coefficient of the proportion of employees older than 49 is still negative and insignificant.

This result might reflect different aspects: First, we might not have found the perfect instrumental variables. One might think for instance of variables measuring the labour supply with respect to different age groups and regions. Therefore, we ran further regressions with the following two instrumental variables: the firm age and the proportion of the labour force aged between 30 and 50 within the total labour force according to different sectors and Bundesländer as a measure of the labour supply that could potentially replace the older workers. However, the impact of the proportion of older workers remains negative and insignificant. Moreover, the coefficient becomes quite large and imprecisely estimated (coefficient -1.685, standard error: 1.408).

Second, our measure of the share of older workers might be too crude. However, due to data limitations we are not able to further differentiate within the age group older than 49. Another aspect is that in fact, during the last couple of years, it has become more difficult to leave the labour market at the age of 50 since on the one hand institutional support such as the unemployment compensation system has been cut back considerably; on the other hand, firms might depend on older workers since the labour force has been shrinking owing to the demographic development.

Third, in 2006, employees at the age of 50 on average had a more advanced educational background and had better computer skills than employees at the age of 50 in the eighties or nineties. Thus, the proportion of older workers might be ‘less endogenous’ than it was still a couple of years ago.

Finally, the study by Aubert and Crépon (2003) for instance discusses extensively the problems involved with consistently estimating the productivity effects of age groups within firms. Although these authors use a large French data set (between 19,000 and 29,000 observations) and apply various estimation methods (including OLS and GMM) and various kinds of standardising the variables (inter and intra firm variations) their results do not reveal that older workers are significantly less productive than prime age workers. By contrast, they find even positive and significant effects for the age groups 50 to 54 and 55 to 59 in the commerce sector and positive and significant impacts for the age group 50 to 54 in the service sector compared to the reference age group of 35 to 39 years old employees, while there is no significant effect in the manufacturing industry.

The exposition of these arguments demonstrates that there is still a lot to investigate in the course of future research. A further aspect not taken into account in this paper is unobserved heterogeneity. The estimations are based on information from two different waves of the data, however, some of the variables are contained in only one of the waves such that fixed effects estimation is not possible.

3.6 Conclusion

The attempt of the paper was to provide empirical evidence on the question whether firms' IT-enabled productivity is lowered by older workers. The theoretical considerations are based on a simple production function framework with heterogenous labour quality. Using firm-level data from German manufacturing and services industries econometric estimations reveal that workers older than 49 are not significantly less productive than prime age workers. Older workers using a computer are more productive than older non-computer users. Interactions between IT intensity and the proportion of older workers show no significant effects, thus, older workers do not lower IT-enabled productivity.

The results reveal that positive productivity effects owing to computer usage at the workplace are not restricted to certain age groups but do also exist for the case of older workers. Moreover, an ageing workforce and technological progress are not necessarily conflicting trends. An efficient allocation of resources combined with measures of lifelong learning may help to reap the potentials inherent in new technologies. Furthermore, it might allow to keep older workers actively in the labour market. Amongst other measures, this could form a solution to future skill shortage due to a shrinking labour force and a depreciation of technological knowledge.

Further research could go in various directions: Firstly, alternative econometric techniques could be applied taking account of endogeneity of the input factors or unobserved heterogeneity. The general method of moments (GMM) as applied for instance by Hempell (2005b) or the method by Olley and Pakes (1996) are potential candidates. However, both techniques need panel data with a longer time horizon. Secondly, a different approach is the frontier production framework allowing to analyse a firm's distance from the technological frontier (see for instance Kumbakhar and Lovell, 2000). It might be interesting to investigate the impact of an ageing workforce on this distance. Thirdly, more detailed information about the ICT applications used by older workers as well as on the task composition of older workers compared to those of their younger counterparts could help to shed more light on the relationship between ICT and the age structure of the workforce and its implications for firm performance. For example, new applications like blogs or wikis for supporting the knowledge management of firms might constitute appropriate tools to combine the experience of older employees and the skills of younger ones in order to increase firms' productivity and innovation capability.

3.7 Appendix

Table 3.4: Distribution of Firms Across Industries in the Samples

	large sample		**small sample**	
Industry	Obs.	Perc.	Obs.	Perc.
consumer goods	92	8.85	71	9.15
chemical industry	56	5.39	40	5.15
other raw materials	82	7.89	63	8.12
metal and machine construction	126	12.13	95	12.24
electrical engineering	75	7.22	53	6.83
precision instruments	86	8.28	68	8.76
automobile	62	5.97	34	4.38
wholesale trade	45	4.33	34	4.38
retail trade	71	6.83	46	5.93
transportation and postal services	61	5.87	42	5.41
banks and insurances	39	3.75	31	3.99
electronic processing and telecommunication	86	8.28	66	8.51
technical services	89	8.57	70	9.02
other business-related services	69	6.64	53	6.83
sum	1039	100	776	100

Source: ZEW ICT survey 2007, own calculations.

Table 3.5: Development of Percentage Shares of Age Groups

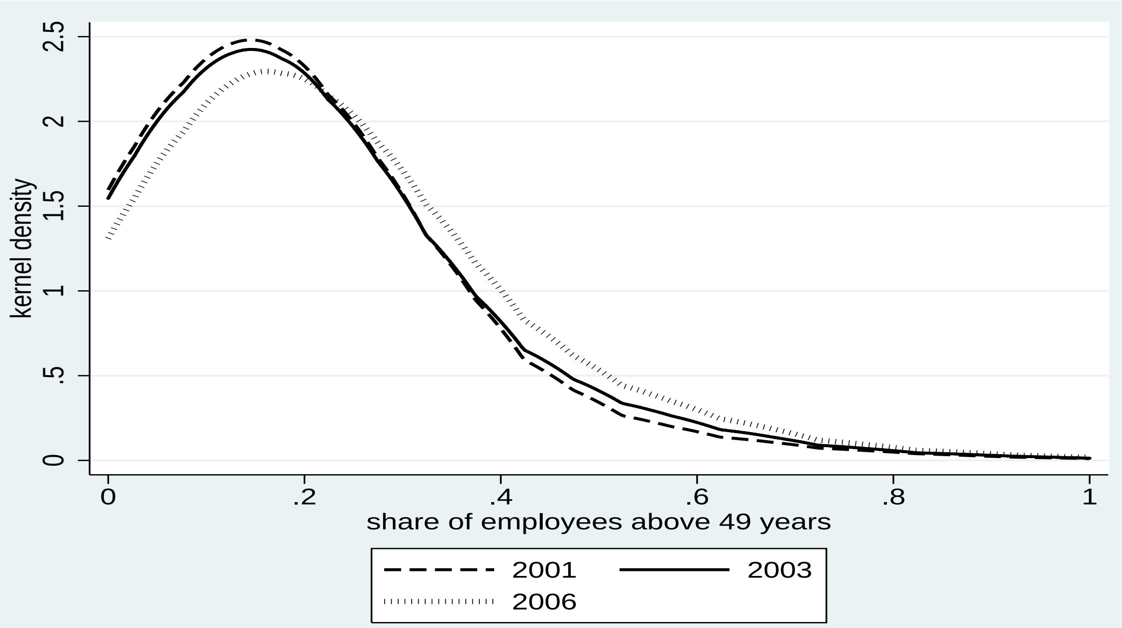
Year	**Variable**	**Obs**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
2001	share of empl. $<$ 30 years	3824	0.290	0.196	0	1
	share of empl. $>$ 49 years	3858	0.181	0.147	0	1
2003	share of empl. $<$ 30 years	3373	0.273	0.188	0	1
	share of empl. $>$ 49 years	3713	0.191	0.156	0	1
2006	share of empl. $<$ 30 years	3718	0.263	0.186	0	1
	share of empl. $>$ 49 years	3744	0.219	0.166	0	1

Source: ZEW ICT surveys 2002, 2004, 2007, own calculations.

Figure 3.1: Kernel Density Estimation: Share of Employees Below 30 Years

Source: ZEW ICT surveys 2002, 2004, 2007; bandwidth=0.1

Figure 3.2: Kernel Density Estimation: Share of Employees Above 49 Years



Source: ZEW ICT surveys 2002, 2004, 2007; bandwidth=0.1

Table 3.6: Coefficients of IV-Estimation

	dependent variable:	
	share of older employees	**log. labour productivity**
	First Stage	IV (2SLS)
firm age	0.0006**	
	(0.0003)	
collective labour	0.035***	
agreement	(0.011)	
share of employees		-0.428
above 49 years		(-0.998)
share of employees	-0.216***	-0.445*
below 30 years	(0.029)	(0.247)
log (employment)	-0.009**	-.109***
	(0.006)	(0.024)
log (gross investment)	0.004	0.137***
	(0.004)	(0.019)
share of high-skilled employees	-0.011	0.517***
	0.040	0.163
share of medium-skilled employees	-0.000	0.352***
	(0.028)	(0.115)
pcwork	-0.031	0.433***
	(0.025)	(0.110)
incentive wages	-0.013	0.122***
	(0.011)	(0.046)
units with P&L responsibility	-0.000	0.105**
	(0.010)	(0.048)
exporting activities	-0.020	0.087**
	(0.012)	(0.051)
dummies for sectors and region	yes	yes
Number of observations	800	800
R^2	0.1666	0.3576

Test on overidentifying restrictions: Score chi2(1)=1.17489 (p=0.2784). Significance levels : $*$: 10% $**$: 5% $***$: 1%. Heteroscedasticity-robust standard errors in parentheses. Reference categories: share of employees between 30 and 49 years, share of low-skilled employees.

4 Does Social Software Support Service Innovation?

4.1 Introduction

Recent Internet technologies and web-based applications, frequently described with the headword web 2.0, do not only penetrate and change the private internet usage and communication behaviour, but are increasingly applied in firms. Social software is part of the term web 2.0, but has up to now no standard definition. It serves in particular the communication, cooperation and information sharing between individuals and includes applications such as blogs, wikis or online communities.[1] Common to all of them is that they are web-based and self-organising. Social software interlinks users and their knowledge and pursues the open content principle. Thereby, it has different potentials of usage.

Due to its application in the knowledge management where it creates knowledge transparency and new knowledge and supports knowledge exchange via a faster access to information, more efficient communication and appropriate tagging and linking, social software has the potential to support the innovative capability of firms. Improved knowledge management hence may lead to the development of new processes and services. Furthermore, social software can be actively applied to viral marketing and customer retention as well as passively to business-intelligence. Therefore, the application of social software to external communication can improve the firm's access to customers and their knowledge and information, i.e.

[1] A blog is a web page where entries are ordered chronologically, beginning with the latest entry and the possibility to comment on the entries. A wiki is a web page where every user can add or change content. An online community is a virtual community of users in the Internet.

its access to external knowledge.

Using data from 505 German Information- and Communication Technology (ICT) and knowledge-intensive service firms, this is the first paper which empirically tests the hypothesis whether the use of social software applications triggers service innovation. Permanent innovation is one of the most important conditions for staying competitive, as has been shown by theoretical approaches like those of Aghion, Bloom, Blundell, Griffith, and Howitt (2005) or Aghion, Blundell, Griffith, Howitt, and Prantl (2006). Although this is true for innovations of the manufacturing industries as well as for those of the service sectors, innovative activities and capabilities of service firms have been empirically less investigated than those of manufacturing firms. The service sector differs from the manufacturing sector with respect to its products and their production and thus there are differences with regard to the innovative behaviour. Service products are intangible and difficult to protect via patents. Furthermore, services are characterised by an intense interactivity between supplier and client and are often produced and consumed at the same time (Evangelista 2000, Miles 2005). The result of these characteristics is a high importance of internal knowledge, embodied in the employees, and of external knowledge, such as information of customers, partner and competitors for innovations in the service sector.

As theoretical framework, a knowledge production function (Griliches 1979, Pakes and Griliches 1984) is employed in which the application of social software constitutes the knowledge sourcing activity. Furthermore, this study tries to identify whether there is a difference between the impact of knowledge sourcing activity focusing on external knowledge and focusing on internal knowledge. In particular, the following questions will be analysed: Are firms which apply social software more likely to innovate? Does the purpose of the social software use affect the probability of service innovation differently or is the effect of internally and externally applied social software the same?

The results of Probit estimations show that ICT and knowledge intensive service firms that use social software are more likely to innovate. Taking into account former innovative activities of the firm and its previous propensity to adopt new technologies and to change processes, the analysis suggests a causality between social software use and innovation that runs from social software to service innovation. There are no robust results on the impact of knowledge sourcing activity focusing on external knowledge and on internal knowledge. This might be due to the data in which only few firms which use social software exclusively for internal or external purposes are observed. Thus, the analysis allows no statement on different impacts of social software use according to its application purpose.

The paper is organised as follows: Section two reviews the literature on service innovation, defines social software, gives some insights on knowledge management and innovation and derives the research question. A description of the data set is given in section three. Section four presents the analytical framework and the empirical strategy. Section five describes and interprets the results. Section six concludes and gives an outlook on further demands on research.

4.2 Background Discussion and Hypothesis Derivation

The analysis and measurement of innovation in services and the distinction between process, product or organisational innovations is difficult (Gallouj and Weinstein 1997, den Hertog 2000). Gallouj and Weinstein (1997) stress two reasons for that. Firstly, innovation theory has been developed on the basis of the analysis of technological innovation in manufacturing. Secondly, the nature of services complicates the use of traditional economic measurements. The nature of services implies the often mentioned features of intangibility, interactivity and coterminality: Service products are harder to store, to transport and to export compared to manufacturing products (intangibility). There is intense interactivity between supplier and client and, in most service processes, both have to be present for the transaction (interactivity). The production and consumption of services occur at the same time and place (coterminality). Thus, innovation may focus more on these particular characteristics (Miles 2005, 2008). According to Gallouj and Weinstein (1997), the two reasons mentioned above led to two complementary groups of studies on innovation in services. The first group focuses on analysing the introduction of technical equipment or IT as a service innovation or at least as a starting point of service innovation.[2] The second group deals with non-technological, service-oriented innovation. Although this paper analyses the relation between IT-use (in this case social software) and service innovation, it refers to the second group because here, IT is not intended to provide the services or to change the quality of service provision, but to improve the connections to the sources of knowledge needed for service innovation.

Innovation in services relies mainly on two important features: the internal knowledge within the organisation and its employees and the external network of the firm including customers and other businesses (Sundbo 1997). Human capital and knowledge about markets, consumer habits and tastes play a crucial role in the strategic asset of a service firm. Clients, customers and suppliers of equipment are important information sources (Evangelista 2000). Tether (2005) identifies these two features as the "softer" sources of innovation, compared to the "hard" sources of technology and knowledge (such as from R&D or acquired technologies), which manufacturers rather place emphasis on. Since the literature on service innovation has grown, there is various empirical evidence on the determinants of service innovation.[3] This literature supports the hypothesis that these "softer" inputs to innovation play a crucial role in service innovation.[4]

Social software is a concept with no hard boundaries. Summarising the literature on social software reveals that social software encompasses web-based applications which link persons and support communication, interaction and cooperation (e.g. Hippner 2006, Alby 2007, Döbler 2007, Raabe 2007, Back and Heidecke 2008). The idea behind social software is mainly based on the web 2.0 principle of harnessing

[2]See for instance Barras (1990), Evangelista, Sirilli, and Smith (1998), Licht and Moch (1999), Evangelista (2000) or Freel (2006).

[3]A great deal of the literature on service innovation considers knowledge-intensive business services (KIBS). Although this paper uses data from ICT- and knowledge-intensive services, it will not focus on the KIBS-literature and the innovation in KIBS. For a review, see for instance Leiponen (2005) or Koch and Strotmann (2006).

[4]See for instance Hipp, Tether, and Miles (2000), Arvanitis and von Arx (2004), Leiponen (2005), Tether (2005), Leiponen (2006), Koch and Strotmann (2006), Schibany, Berger, Streicher, and Gassler (2007), Arvanitis (2008) and Love, Roper, and Hewitt-Dundas (2008).

collective intelligence.[5] Thus, to fulfil its purpose to link persons and to support communication, interaction and cooperation among them, social software uses the potential, contributions and knowledge of a network of participants (Back and Heidecke 2008). Social software is self-organised, transparent and supports social feedback (Hippner 2006, Alby 2007, Raabe 2007). From most authors' points of view, applications such as wiki, blog, web forum (discussion forum, internet forum), instant messaging, social bookmarking, folksonomy, social networks (online communities), podcast (vodcast) and vlog can be assigned to social software.[6]

Commonly, ICT-applications are employed in firms before they diffuse into private usage. However, considering social software, the reverse is true. Applications such as wikis, blogs and social networks have been applied by private users before diffusing into firms. Within a firm, social software can be applied for different purposes. On the one hand, it can be used for external communication or for customer relationship management, marketing, market research or cooperations with other firms and partners. On the other hand, it can be utilised for internal communication, including for example knowledge management, project management or product development.[7] This paper focuses on social software as a knowledge management tool. Thereby, social software has two functions: the pooling and management of internal knowledge and the enabling of access to external knowledge.

As pointed out, internal and external knowledge is important for service innovation. The cooperation with externals needs to be sustained by enabling access to their knowledge. The particularities of knowledge and its importance in the innovation process require appropriate management. The knowledge management concept developed by Probst, Raub, and Romhardt (2006) consists of eight components: knowledge goals, identification, acquisition, development,

[5] O'Reilly (2005) coined and clarified the term web 2.0 in his seminal article. According to him, the basic characteristics of applications typical for web 2.0 are: the web as a platform, harnessing collective intelligence, data-driven applications, end of the software release circle ("perpetual beta"), lightweight programming models, software above the level of a single device and rich user experiences.

[6] See for instance Alby (2007) and Hippner (2006) for a definition of these applications.

[7] See for instance Raabe (2007), Döbler (2008) and the articles in Hildebrandt and Hofmann (2006) or in Back, Gronau, and Tochtermann (2008) for details, case studies and examples of the social software adoption in several business areas.

dissemination, use, preservation and evaluation. Social software could be used for every component of this knowledge management concept. For instance, the transparency inherent in social software can support knowledge identification. Knowledge acquisition can be supported by connecting with partners and customers via social networks. Wikis or blogs could be useful for knowledge dissemination and preservation because on the one hand, they store information and on the other hand, they make it accessible for others. Knowledge evaluation could be supported by the social feedback function of social software. The knowledge spiral by Nonaka and Takeuchi (1997) shows how knowledge is transferred and new knowledge is created within a firm. Knowledge can be subdivided into implicit knowledge, which is personal, context-specific and thus hard to communicate, and explicit knowledge, which can be passed on in a formal and systematic language. The knowledge spiral consists of four phases: socialisation (implicit knowledge is transferred into implicit knowledge), externalisation (implicit knowledge is transferred to explicit knowledge), combination (explicit knowledge is transferred into explicit knowledge) and internalisation (explicit knowledge is transferred into implicit knowledge). Social software could support parts of the four phases. The externalisation process is caused by a constructive dialogue that externalises implicit knowledge via joint metaphors or analogies. The tagging of contents and creation of tag clouds for particular topics might support the externalisation. The combination is created by connecting new and existing knowledge to build for instance a new service or management system. The commentating of existing content and the linking of different contents are a function of social software that could facilitate the combination phase.

Although knowledge plays the key role in innovation, the empirical work on the relationship between knowledge management and innovation is rather scarce and little developed (Hall and Mairesse 2006). There is some literature that finds a positive correlation between the use of knowledge management practices and innovation: e.g. Darroch (2005), who uses a total of 16 factors, such as valuing employees attitudes and opinions and encouraging employees to up-skill, using techniques such as quality circles, case notes, mentoring and coaching to disseminate knowledge or responding to knowledge about customers, competitors and technology, to identify knowledge management. One of these factors representing knowledge management is the use of technology (such as teleconferencing, videoconferencing and Groupware) to facilitate communication and disseminate knowledge. The correlation between technology as a management tool and radical innovation is positive. However, Darroch and McNaughton (2002) find a positive impact for less than half of their knowledge management measures only. Cantner, Joel, and Schmidt (2009) find a positive effect regarding the application of knowledge management connected to innovative success. Firms which apply knowledge management achieve higher shares of turnover with innovative products. They focus on six collaborative (between departments) knowledge management techniques, such as joint development of innovation strategies, open communication of ideas and concepts among departments or temporary exchange of personnel. In their measurement, firms with knowledge management activities have to perform at least three of the six knowledge management tools. Czarnitzki and Wastyn (2009) use three different knowledge management practices to analyse different innovation outputs. They find that stimuli for active knowledge sharing among employees have a positive impact on unit cost reduction by process innovations. The acquisition of external knowledge and codified knowledge management policy have a positive effect on the introduction of new products or services and codified knowledge management policy also positively affects market novelty innovations.

Furthermore, there are a few studies, based on theoretical considerations, case studies or use cases, which analyse the employment of information technology in knowledge management and collaboration and its relation to innovation and product development (see for instance Adamides and Karacapilidis 2006, Christensen, Magnusson, and Zetherstrom 2006, Sethi, Pant, and Sethi 2003). There is some case study evidence on the adoption of social software, mainly wikis and blogs, in the knowledge management of several firms (e.g. Müller and Dibbern 2006, Ehms 2008, Hilzensauer and Schaffert 2008). To the best of my knowledge, none of the studies analyzing the relationship between knowledge management and innovation have considered social software as a knowledge management tool. Furthermore, the studies on social software adoption in the knowledge management have not considered its impact on innovation. Hence, there is no empirical evidence on the use of social software as a knowledge management tool and its impact on service innovation — this paper closes this research gap.

Based on theoretical considerations, I expect a positive relationship between social software and innovation: Social software can be used as an adequate knowledge management and knowledge sourcing tool as it not only supports the internal knowledge preservation, dissemination and creation, but also the acquisition of external knowledge. If knowledge is a prerequisite for innovation and social software bundles and manages knowledge, then social software should support service innovation. Since internal and external knowledge are two different sources of knowledge, they might have a different impact on service innovation. Thus, there might be a difference regarding the impact of social software use on innovation depending on whether social software is used for internal or external purposes.

4.3 Data Description

The data used for the empirical analysis is taken from the quarterly business survey among the "service providers of the information society" conducted by the Centre for European Economic Research (ZEW) in cooperation with the credit rating agency Creditreform. The sector "service providers of the information society" comprises nine industries belonging to the information and communication technology service providers (e.g. software and IT services) and the knowledge-intensive service providers (e.g. tax consultancy and accounting).[8] Every quarter, a single-page questionnaire is sent to about 3,500, mostly small- or medium-sized, firms. This random sample is stratified with respect to company size, region and sector affiliation. In each wave, the survey achieves a response rate of about 25%. The questionnaire is divided into two parts. In the first part, firms assess their current business development with respect to the previous quarter as well as their expectations for the next quarter. The second part is dedicated to questions concerning ICT usage and further economic issues, such as innovative activities or training behaviour. The questions of the second part change quarterly with selected questions being repeated annually. The survey is designed as a panel. The detailed questions on the use of social software as well as on innovations were asked for the first time. Therefore, panel data estimations such as fixed effects or random effects cannot be provided. This paper uses the data collected in the first and second quarter of the year 2008. The wave of the first quarter of 2008 contains

[8] For further details on the nine industries, their industrial classification and their distribution within the sample, see the data description and Table 4.7 in the appendix.

information on the use of social software and the wave of the second quarter of 2008 comprises data on the innovation activities. The two waves are merged. Considering item non-response for social software and innovation, a sample of 505 firms remains.

Former waves of the data have previously been used to analyse for instance the productivity effects of organisational change (Bertschek and Kaiser 2004), the relationship between managerial ownership and firm performance (Müller and Spitz-Oener 2006) and the impact of the age structure of the workforce on technology adoption (Meyer 2009).

As already noted, it is difficult to measure innovation in services and to distinguish between process, product or organisational innovations. Furthermore, the self-assessment of service firms regarding their innovative activity adds to this difficulty. Hipp, Tether, and Miles (2000) show that the self-assessment of the firms about the kind of innovation accomplished and the classification made by one of the authors differed. Thus, instead of asking firms if they innovated, it seems to be more appropriate to ask them about activities that are supposed to be service product innovations including some specific examples. Thus, we have two dummy variables representing service innovation activities: broadening and differentiation of the range of services offered. Broadening means that the firms broadened their services offered during the last twelve months, e.g., they opened up a new market segment or new customer groups. Differentiation of the offered services means for instance additional offers or changed service hours. On the basis of these two variables, a dummy variable is created, which takes the value one if at least one of the two types of innovation, broadening or differentiation of services offered, has taken place in the last twelve months. This dummy variable represents innovation and is the dependent variable of the empirical analysis. Almost half of the firms were innovative, as Table 4.1 shows. About 50 percent of the firms made at least one of the two changes with regard to their range of offered services. About 39 percent of the firms broadened and about 34 percent differentiated the range of services offered.

Table 4.1: Descriptive Statistics: Innovative Activity

variable	percentage of firms	number of observations
broadening of offered services	39.21	505
differentiation of offered services	34.21	494
at least one innovation	49.90	505

Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

The applications named social software are a rather new phenomenon and are often referred to as web 2.0 applications. That is why the firms were offered a list of applications and were asked if they used them instead of being asked questions about the use of social software in general. Hence, the variable representing the use of social software is a dummy variable which takes the value one if at least one of the following applications were used: blogs, wikis, discussion forums, online communities, teamwork platforms and other applications. This dummy variable represents the main explanatory variable of the empirical analysis. Table 4.2 shows descriptive statistics of the usage behaviour of the firms concerning social software. About 35 percent of the firms use at least one of the above mentioned applications. The most frequently used applications are online communities, also known as social networks. About 19 percent of the firms use online communities. Teamwork platforms ranked second and are utilised by about 16 percent of the firms. About 13 percent of the firms use discussion forums or wikis. Blogs and other applications play a minor role for the firms in the sample. About seven percent of the firms use blogs and about three percent apply other social software. These descriptive numbers indicate that social software is rather applied for communication and cooperation purposes, as applications which serve these aims are favoured.

This indirect inference is supported by what the firms said the purpose of the social software use is (see Table 4.3). About 55 percent of the firms that apply at least one social software use it for internal communication and about 49 percent for internal knowledge exchange. The second most important purpose of social software use is external communication and, close to that, customer relationship support. About 38 percent of the firms use social software for external communication and about 35 percent use it for building and supporting customer relationships. Social software aiming at stimulating innovation and increasing the efficiency of business processes is applied by about 31 and 32 percent, respectively.

Table 4.2: Descriptive Statistics: Use of Social Software

variable	percentage of firms	number of observations
online community	18.70	492
teamwork platform	15.96	495
discussion forum	13.43	484
wikis	13.11	488
blogs	7.20	486
other social software appl.	3.32	482
at least one social software appl.	35.05	505

Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

Social software plays a minor role with regard to work on joint projects, advertisement for new products and other purposes. About 25 percent of the firms apply social software for joint projects, about eleven percent advertise for new products with social software and only about one percent of the firms use social software for other purposes.

Table 4.3: Descriptive Statistics: Purpose of Social Software Use

variable	percentage of firms	number of observations
internal communication	55.37	177
internal knowledge exchange	49.15	177
external communication	37.85	177
composition/support of customer relationships	35.03	177
more efficient business processes	32.20	177
innovation stimulation	31.07	177
joint projects with other firms or freelancers	24.86	177
advertisement for new products	11.30	177
other purposes	1.13	177

Only firms which use at least one social software application. Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

Most of the firms use social software for internal as well as for external purposes. Internal purposes are internal communication, internal knowledge exchange, more efficient business processes and innovation stimulation. External communication, composition and support of customer relationships, work on joint projects with other firms or freelancers and advertisement for new products belong to the external purposes. Only about 16 percent of the firms apply social software exclusively for one

Table 4.4: Descriptive Statistics: Purpose of Social Software Use, Internal versus External Purposes

variable	**percentage of firms**	**number of observations**
no social software	67.63	328
social software for internal purposes only	10.10	49
social software for external purposes only	5.57	27
social software for both purposes	16.70	81
sum	100.00	485[a]

Source: ZEW Quarterly business survey among service providers of the information society, own calculations. [a] The reduction of observations to 485 is due to firms indicating that they use social software without answering the question for what purpose or ticking the option "other purposes".

of both purposes. As Table 4.4 shows, about 68 percent of the firms do not use social software at all. About ten percent of the firms in the sample use social software for internal purposes only. About six percent use social software exclusively for external purposes. Social software is applied for both purposes by about 17 percent.

4.4 Analytical Framework and Estimation Strategy

Griliches (1979) introduced the concept of the knowledge production function, which explains the production of new knowledge by the use of specific input factors. Past and current R&D (Griliches 1979), the research activity (e.g. Geroski 1990) or the research intensity and capital, have been seen as main input factors in the knowledge production function, respectively (e.g. Crépon, Duguet, and Mairesse 1998, Griffith, Huergo, Mairesse, and Peters 2006). Knowledge is commonly proxied by innovation output, measured as product or process innovation indicators such as the introduction of new or significantly improved products or processes (Griffith, Huergo, Mairesse, and Peters 2006), patents, innovation counts (Acs, Anselin, and Varga 2002) or the share of innovative sales (Crépon, Duguet, and Mairesse 1998). Thus, the knowledge production function is often referred to as the innovation production function. Recent literature, using the knowledge or innovation production function, focuses not only on R&D indicators but also on other knowledge sources and routes by courtesy of which the ingredients of innovation activity can be obtained.[9] Freel (2006) uses a modified innovation production function where innovation is a function of internally and externally sourced technological competence alongside direct measured firm R&D. In their model of the innovation value chain, Roper, Du, and Love (2008) identify an innovation production function in which knowledge sourcing activities such as in-house R&D, forward linkages to customers, backward links to either suppliers or external consultants, horizontal linkages to either competitors or through joint ventures and linkages to universities or other public research centres constitute an important input. Studies using data of the Community Innovation Survey (CIS) and analysing the innovation activities of manufacturing firms, also employ cooperation variables (e.g. Janz, Lööf, and Peters 2004) or variables representing internal and external sources of knowledge for innovation (e.g. Lööf and Heshmati 2002) to explain innovation behaviour.

Following these newer approaches of the knowledge production framework, I assume the following knowledge or innovation production function:

$$i_i = \alpha + \beta ks_i + \gamma' x_i + \epsilon_i, \qquad i = 1, \ldots, N \text{ firms} \tag{4.1}$$

where knowledge i_i is proxied by a service innovation indicator. It is a dummy variable which takes the value 1 if the firm has broadened or differentiated its services offered and 0 if the firm did not change its services supply. Due to the binary character of the dependent variable, I estimate a Probit model.[10] The variable ks_i indicates the knowledge sourcing or research activity that is proxied by the dummy variable representing the use of social software and β is the associated coefficient. The coefficient vector γ is associated with the vector x_i including other variables explaining the knowledge production as well as control variables.[11]

[9] Love and Roper (1999) use an extended model of innovation activity and identify three main routes by means of which to obtain main ingredients for innovation: R&D, technology transfer (intra-firm phenomenon) and networking (involves inter-firm relationships), which in turn are the main inputs in their innovation production function. Acs, Anselin, and Varga (2002) implement a Cobb-Douglas function with two inputs as their knowledge production function. These two inputs are industry R&D and university research.

[10] For more details on the Probit model see Wooldridge (2002). All calculations and estimations of this paper were done with STATA 10.0.

[11] Summary statistics of the variables can be found in Table 4.8 in the appendix.

The logarithm of the number of employees represents the firm size and the age of the firm is measured in years. Larger firms tend to have more lines of activity and therefore more areas in which they can innovate (Hipp, Tether, and Miles 2000) and larger firm size increases the chances of innovation if there are significant increasing returns to scale in innovation activities (Leiponen 2005, 2006). The relationship between firm age and innovation is not clear (Katila and Shane 2005). On the one hand, organisations might lose their adaptability to their environment with an increasing age and on the other hand, organisational aging might increase innovativeness due to learning processes (Koch and Strotmann 2006).

The competitive situation is reflected by three dummy variables representing the number of main competitors according to the firms' self-assessment: zero to five competitors, six to twenty competitors (reference category) and more than 20 competitors. The relationship between innovation and competition is supposed to look like an inverted U (Aghion, Bloom, Blundell, Griffith, and Howitt 2005). A monopolist has less incentives to innovate because it has a flow of profit that it enjoys and in a competitive situation, there are less incentives to innovate if there is no possibility to fully reap the returns of the innovation (Gilbert 2006). The share of employees working mainly at a PC is a proxy for the IT intensity of the firm. IT, as general purpose technology (Brynjolfsson and Hitt 2000), and its productive use is closely linked to complementary innovations within firms (Hempell 2005a). It can also be used to improve the quality of services (Licht and Moch 1999).

The structure of the workforce is represented by three variables accounting for the qualification level and three variables accounting for the age. The shares of highly qualified (university or university of applied sciences degree), medium qualified (technical college degree or vocational qualification) and low qualified (other) employees represent the qualification structure. The share of low qualified employees is the reference category. Qualification is a premise for the starting and enhancements of innovations, because without the suitable know-how neither the introduction nor the execution of innovations can be done successfully. The age structure of the workforce is represented by the share of employees younger than 30 years (reference category), the share of employees aged 30 to 55 years and the share of employees older than 55 years. The age of the employees might have an impact on the firms innovative behaviour for two reasons (Meyer 2009): On the one hand, the process of aging leads to a cutback of fluid intelligence which is needed amongst others for new solutions and a fast processing of information. On the other hand, older workers may resist to innovation when their human capital depreciates.

Former innovations are taken into account for two reasons: Firstly, innovation experience plays an important role in explaining innovative behaviour. Innovating, in particular successful innovating, increases the probability of innovating again (Flaig and Stadler 1994, Peters 2007, Peters 2009). Secondly, there might be an endogeneity problem. On the one hand, it is not clear whether firms that use social software are more innovative or whether innovative firms tend to use new and innovative applications such as social software. On the other hand, social software might not only reflect the knowledge sourcing activity but also a firm's general openness to the use of new technologies and its propensity to change processes. Since the data offers no appropriate instruments to control for this potential endogeneity, former innovations are considered to control for innovativeness and openness to the use of new technologies in general and thus to weaken the endogeneity problem. We have two dummy variables that represent former product and process innovation, respectively.[12] Former product innovation takes on the value one if the firm introduced at least one new or significantly improved service between the third quarter of 2004 and the first quarter of 2007. Former process innovation and thus a general openness to new technologies and changes in the process, takes on the value one if the firm adopted new technologies during this period.

Nine sector dummies are considered to control for industry-specific fixed effects. A dummy variable for East Germany is incorporated to account for potential regional differences. The error term ϵ_i covers all unmeasured (unobserved) influences on knowledge.

[12] In the third quarter of 2005 and first quarter of 2007 the firms were asked "Have you offered a new or significantly improved service during the last twelve months?" (product innovation) and "Have you adopted new or significantly improved technologies (e.g. new data processing systems, Internet) in your company during the last twelve months?" (process innovation).

In a second step, the fact that knowledge can be sourced internally and externally is taken into account. Following Freel (2006) who considers two vectors of internally and externally sourced technological competence, the knowledge or innovation production function is extended in the following way:

$$i_i = \alpha + \beta_1 ksint_i + \beta_2 ksext_i + \gamma' x_i + \epsilon_i, \qquad i = 1, \ldots, N \text{ firms} \tag{4.2}$$

where $ksint_i$ represents internally sourced knowledge proxied by the use of social software for internal purposes and $ksext_i$ indicates externally sourced knowledge measured by the use of social software for external purposes. All other variables and coefficients stay the same as in equation (4.1). Since there are only few firms which use social software for exclusively one of the two purposes (see Table 4.4), four dummy variables are created for the estimation and taken into account: one for no use (reference category), one for exclusively internal purposes, one for exclusively external purposes and one for applying social software for both purposes.

4.5 Empirical Results

Table 4.5 reports the marginal effects of the Probit estimation of equation (4.1).[13] The results show that firms which use social software are more likely to innovate than firms which do not use social software. This result is robust across different specifications shown in Table 4.5. Firms that use social software have a probability of innovating that is about 16.4 percentage points larger than the probability of firms that do not use social software (see last row of Table 4.5). Since there is no econometric evidence on the adoption of social software and service innovation so far, the results cannot be directly compared to former studies. However, Darroch (2005) finds a positive relation between knowledge management and innovation. The correlation coefficients of the significant knowledge management measures are between 0.13 and 0.27 for innovation types new to the world and between 0.16 and 0.47 for innovation types new to the firm. Darroch and McNaughton (2002) find a positive impact for less than half of their knowledge management measures only. The significant coefficients of their ordinary least squares regression lie between 0.09 and 0.34 and the coefficient of the measure "organisation is flexible and

[13] Only the average marginal effects (sample averages of the changes in the quantities of interest evaluated for each observations) are discussed in the following. A table containing the coefficient estimates is available upon request.

opportunistic" is 0.54 for incremental innovations. Considering the use of social software as a knowledge sourcing tool, the results are in line with the literature that finds a positive relation between internal and, in particular, external knowledge trough cooperation (e.g. Arvanitis and von Arx 2004, Leiponen 2005, Freel 2006, Koch and Strotmann 2006, Leiponen 2006).

Table 4.5: Average Marginal Effects of Probit Estimations, Social Software

dependent variable: dummy for innovation					
	(1)	(2)	(3)	(4)	(5)
social software	0.162***	0.114**	0.141***	0.141***	0.164**
	(0.046)	(0.047)	(0.049)	(0.053)	(0.068)
firm size		0.075***	0.084***	0.082***	0.059**
		(0.017)	(0.018)	(0.020)	(0.023)
firm age		-0.009***	-0.009***	-0.009***	-0.008**
		(0.002)	(0.002)	(0.003)	(0.003)
IT intensity			-0.109	-0.147	-0.235*
			(0.085)	(0.096)	(0.123)
competitors 0-5			0.075	0.047	0.031
			(0.058)	(0.061)	(0.073)
competitors >20			0.071	0.063	0.126*
			(0.056)	(0.059)	(0.071)
highly qualified empl.				0.322	0.110
				(0.209)	(0.226)
medium qualified empl.				0.272	-0.027
				(0.206)	(0.212)
employees 30-55 years				-0.153	-0.074
				(0.141)	(0.179)
employees >55 years				0.299	0.319
				(0.201)	(0.258)
former product inno.					0.255***
					(0.061)
former process inno.					0.122**
					(0.062)
sector dummies		***	**	**	***
regional dummy		-0.058	-0.051	-0.054	-0.052
obs.	505	495	454	415	248
Pseudo R^2	0.02	0.10	0.11	0.12	0.26

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses.
Reference categories: competitors 6-20, unqualified employees, employees $<$ 30 years.

Furthermore, the results reveal that firms which are larger in terms of employment and firms which are younger have a higher propensity to innovate. Literature on firm age and service innovation finds rather no significant impact (e.g. Koch and Strotmann 2006, Peters 2009) or weak evidence for a negative relationship, e.g. Freel (2006), who finds that technology-based knowledge intensive business services between four and nine years old are less likely to innovate than older ones or Rogers (2004), who finds a significantly negative impact of firm age on innovation in non-manufacturing firms only for small firms with less than five employees. The IT intensity of a firm, represented by the share of employees working mainly with a computer, is negatively significant at the ten percent level but only in the last specification. The competitive situation of a firm has no significant impact apart from specification (5) where the dummy variable for more than 20 competitors is positive at the ten percent significant level. The employees' age and qualification structure and the region East Germany have no significant impact on the probability of innovating. The results in the last row of Table 4.5 show that firms which have been innovative before are more likely to innovate again.[14] Thereby, the effect of former service product innovation is higher than the effect of former process innovation, that is the adoption of new technologies. Due to an insufficient panel structure, the consideration of former innovations reduces the sample size to 248 observations. All specifications have also been estimated using this small sample. Table 4.9 in the appendix contains the marginal effects of these estimations. The results regarding the use of social software did not change qualitatively. However, the dummy variable for more than 20 competitors turns out to be positively significant at the ten percent level.

The potential reverse causality between service innovation and social software use and the problem whether social software measures openness to new technologies and changing processes cannot be solved econometrically due to the lack of appropriate instruments in the data. Nevertheless, since the positive effect of social software use does not diminish when former product innovations are taken into account, the problem of potential reverse causality can be put into perspective. The measurement problem can be relativized as well, since the positive effect of social software use is still there when considering former process innovation, that is the adoption of new technologies and applications. When

[14]The same regression has also been run, including only the dummy variable for former product innovation, with including only the dummy variable for former process innovations and including only a variable representing at least one of the two. The results did not change qualitatively and are available upon request.

former product innovations are considered as a proxy for general propensity to be innovative and former process innovations are seen as a proxy for being keen on new applications and technologies, then the results suggest that the causality runs from social software use to service innovation.

Table 4.6 shows the marginal effects of the Probit estimation considering not only the impact of social software but also whether it is used for internal or external purposes.[15] Compared to firms that do not use social software, firms that use social software for external purposes exclusively are more likely to innovate (see specification (1)). In the second specification, the significance level of this variable drops to ten percent and in specification (3), the variable becomes insignificant. The dummy variable representing social software use for exclusively external purposes is significant at the ten percent level in specification (4) and then again turns insignificant in the last specification. Thus, the results regarding the impact of exclusively externally used social software on innovation are not clear and allow no statement on the impact of exclusively externally used social software on service innovation. This might be due to the data structure and few observations of this variable: Only 27 firms out of 485 claim to use social software exclusively for external purposes (see Table 4.4). The dummy variable representing social software use for exclusively internal purposes is not significant at all.

To check the robustness, all estimations were done on basis of the smallest sample of 237 observations (specification (5)). Table 4.10 in the appendix contains the marginal effects of these estimations. The dummy for external social software use is not significant at all whereas the dummy for internal social software use is positively significant at the ten percent level in specifications (1) and (2) and at the five percent level in specifications (3) and (4). In the last specification, the dummy for exclusively internally social software use becomes insignificant. This again might be due to the distribution of the four dummy variables. There are only nine observations left that use social software exclusively for external purposes compared to 25 observations using these applications exclusively internally compared to 39 observations using social software for both.

[15] A table containing the coefficient estimates is available upon request.

Table 4.6: Average Marginal Effects of Probit Estimations, Purposes of Social Software Use

dependent variable: dummy for innovation					
	(1)	(2)	(3)	(4)	(5)
social software internal	0.106	0.063	0.128	0.119	0.142
	(0.073)	(0.075)	(0.078)	(0.083)	(0.094)
social software external	0.216**	0.173*	0.150	0.163*	0.150
	(0.088)	(0.090)	(0.094)	(0.139)	(0.141)
social software both	0.208***	0.144**	0.172***	0.168**	0.227***
	(0.058)	(0.062)	(0.063)	(0.069)	(0.085)
firm size		0.073***	0.079***	0.081***	0.058**
		(0.017)	(0.018)	(0.021)	(0.024)
firm age		-0.009***	-0.010***	-0.010***	-0.009***
		(0.002)	(0.002)	(0.003)	(0.003)
IT intensity			-0.087	-0.126	-0.259**
			(0.087)	(0.098)	(0.125)
competitors 0-5			0.084	0.053	0.032
			(0.059)	(0.062)	(0.075)
competitors >20			0.079	0.067	0.128*
			(0.056)	(0.059)	(0.072)
highly qualified empl.				0.371*	0.166
				(0.213)	(0.230)
medium qualified empl.				0.315	0.024
				(0.210)	(0.215)
employees 30-55 years				-0.107	0.003
				(0.144)	(0.183)
employees >55 years				0.335	0.381
				(0.204)	(0.266)
former product inno.					0.266***
					(0.063)
former process inno.					0.089
					(0.064)
sector dummies		***	**	*	**
regional dummy		-0.059	-0.049	-0.062	-0.061
obs.	485	475	436	398	237
Pseudo R^2	0.02	0.10	0.12	0.12	0.27

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses. Reference categories: no social software, competitors 6-20, unqualified employees, employees $<$ 30 years.

At first sight, the analysis suggests that the purpose which social software is applied for does not matter, although there is a slight tendency that exclusively externally used social software has a positive impact rather than exclusively internally used social software. That hints to greater importance of external knowledge compared to internal knowledge for service innovation. However, the result is not robust across the different specifications and sample sizes. Using a smaller sample on the other hand suggests the opposite: a greater importance of internally sourced knowledge for service innovation. The reason for these inconsistent results may be due to the data structure and the fact that very few firms use social software exclusively for internal or external purposes. Thus, the analysis does not allow making any statement on the differences between internally and externally used social software and their impact on service innovation.

Furthermore, the results in Table 4.6 reveal that firms which use social software for internal as well as for external purposes are more likely to innovate compared to firms which do not apply social software. Thus, the general result that firms which use social software are more likely to innovate compared to non-using firms is approved. However, the marginal effect is larger compared to the estimation results in Table 4.5. It lies between 0.227 and 0.144, depending on the specification.

Table 4.6 also approves the findings of Table 4.5 with regard to firm size, firm age, IT intensity, competitive situation and former product innovation although the effects slightly differ in magnitude. However, there are also differences between the results of the estimation considering social software use in general and the results of the estimation regarding the purpose of social software use: The variable share of highly qualified employees is positively significant at the ten percent level in specification (4) and the dummy variable representing former process innovations is insignificant in Table 4.6. Latter results are not robust. When assuming that the 20 firms for which there is no statement on the purpose of the social software use are employing social software for both purposes and estimating all specifications with this variable instead, then the share of highly qualified employees changes to being insignificant in specification (4) and dummy for process innovation changes to being significant.[16]

To summarise the results: ICT and knowledge intensive service firms that use social software are more likely to innovate in terms of broadening and/or differentiation in services supply. The problem of potential reverse causality between social software

[16]A table of results is available on request.

use and innovativeness cannot be solved econometrically. However, since innovativeness in general, proxied by former innovations, has been controlled for in the estimations, the results suggest a causality that runs from social software to innovation. The problem that social software might not only reflect the knowledge sourcing activity but also a firm's general openness to the use of new technologies and its propensity to change processes, does not weigh that heavy, since taking into account former process innovation to control for a general openness to the use of new technologies, does not change the results regarding the use of social software. The estimation results on the impact of social software used exclusively internally and exclusively externally are ambiguous and not robust across different specifications and sample sizes. Thus, the empirical results do not allow making any statements on whether there are differences in the impact of social software use on service innovation according to their application purpose. However, firms that apply social software for both purposes are more likely to innovate. This, in turn, approves the result on the positive impact of social software use on service innovation.

4.6 Conclusion

This paper analyses the relationship between the use of social software and service innovation. Social software can be applied for knowledge management and for external communication where it enables access to internal as well as to external knowledge. Knowledge in turn constitutes one of the main inputs to service innovation. Furthermore, this paper tries to identify if there is a difference between the impact of knowledge sourcing activity focusing on external knowledge and focusing on internal knowledge. The analysis refers to a knowledge production function in which the application of social software constitutes the knowledge sourcing activity. The empirical analyses are based on data of about 505 firms in the ICT- and knowledge-intensive business services sector.

The econometric results reveal that there is a positive relationship between the use of social software and service innovation, measured as broadening or differentiation of the range of services offered. Firms applying at least one social software application are more likely to innovate compared to firms which do not use social software. There is an endogeneity problem: On the one hand, it is not clear whether firms that use social software are more innovative or whether innovative firms tend to use new and innovative applications such as social software. On the other hand, social software might not only reflect the knowledge sourcing activity but also a firm's general openness to the use of new technologies and its propensity to change processes. However, since innovativeness in general, proxied by former product innovations, has been controlled for in the estimations, the results suggest a causality that runs from social software to innovation and thus that social software supports service innovation. Considering former process innovation, that is the adoption of new technologies and applications, does not change the results and thus, the measurement problem can be put into perspective.

The estimation results on the impact of exclusively internally and exclusively externally used social software are ambiguous and differ across different specifications and sample sizes. Thus, it is not possible to make any statements on whether there are differences in the impact of social software use on service innovation according to their application purpose. Furthermore, the paper finds that firms which are larger in terms of employment and younger are more likely to innovate. The results also confirm the success breeds success hypothesis, that firms which have been innovative before are more likely to innovate again.

The current analysis sheds light on the relationship between social software and service innovation. However, the question whether social software supports service innovation needs further research. In particular, the question of causality needs to be answered, since with the current data, this problem cannot be solved econometrically and thus, the results only hint at a causality that runs from social software to innovation. Due to few firms indicating that they use social software exclusively for internal or exclusively for external purposes, the variables representing them are insufficient for making a robust and consistent empirical analysis. With a larger and more detailed data set it might be possible to analyse these two channels to add more evidence to the role of internal and external knowledge in service innovation and how to exploit them.

4.7 Appendix

The ZEW quarterly business survey among service providers of the information society includes the following industries (codes of the German Classification of Economic Activities, Edition 2003 in parentheses): software and IT services (71.33.0, 72.10.0-72.60.2), ICT-specialised trade (51.43.1, 51.43.3-3.4, 51.84.0, 52.45.2, 52.49.5-9.6), telecommunication services (64.30.1-0.4), tax consultancy and accounting (74.12.1-2.5), management consultancy (74.11.1-1.5, 74.13.1-3.2, 74.14.1-4.2), architecture (74.20.1-0.5), technical consultancy and planning (74.20.5-0.9), research and development (73.10.1-73.20.2) and advertising (74.40.1-0.2). Table 4.7 shows, how the industries are distributed in the sample of 505 observations.

Table 4.7: Distribution of Firms Across Industries in the Sample

Industry	**Observations**	**Percentage**
software and IT services	80	15.84
ICT-specialised trade	46	9.11
telecommunication services	16	3.17
tax consultancy and accounting	90	17.82
management consultancy	52	10.30
architecture	76	15.05
technical consultancy and planning	44	8.71
research and development	58	11.49
advertising	43	8.51
sum	505	100

Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

Table 4.8: Descriptive Statistics: Total Sample

Variable	Mean	Std. Dev.	Min.	Max.	N
number of employees	67.034	277.485	2	4000	505
log(number of employees)	2.85	1.359	0.693	8.294	505
firm age	16.931	10.349	0	93	495
0-5 competitors	0.286	0.452	0	1	472
6-20 competitors	0.288	0.453	0	1	472
more than 20 competitors	0.426	0.495	0	1	472
share of empl. working with PC	0.784	0.295	0	1	493
share of highly qualified empl.	0.412	0.307	0	1	476
share of medium qualified empl.	0.53	0.299	0	1	476
share of low qualified empl.	0.058	0.12	0	1	476
share of empl. $<$ 30 years	0.198	0.183	0	1	485
share of empl. 30 - 55 years	0.671	0.197	0	1	485
share of empl. $>$ 55 years	0.13	0.144	0	1	485
former product inno.	0.431	0.496	0	1	295
former process inno.	0.416	0.494	0	1	308

Source: ZEW Quarterly business survey among service providers of the information society, own calculations.

Table 4.9: Average Marginal Effects of Probit Estimations, Social Software Reduced Sample

dependent variable: dummy for innovation					
	(1)	(2)	(3)	(4)	(5)
social software	0.222***	0.171**	0.211***	0.200***	0.164**
	(0.064)	(0.067)	(0.068)	(0.069)	(0.068)
firm size		0.073***	0.070***	0.074***	0.059**
		(0.024)	(0.024)	(0.024)	(0.023)
firm age		-0.009***	-0.009***	-0.009***	-0.008**
		(0.003)	(0.003)	(0.003)	(0.003)
IT intensity			-0.122	-0.211	-0.235*
			(0.116)	(0.132)	(0.123)
competitors 0-5			0.060	0.055	0.031
			(0.078)	(0.077)	(0.073)
competitors >20			0.139*	0.125*	0.126*
			(0.072)	(0.073)	(0.071)
highly qualified empl.				0.295	0.110
				(0.241)	(0.227)
medium qualified empl.				0.153	-0.027
				(0.225)	(0.212)
employees 30-55 years				-0.145	-0.074
				(0.189)	(0.179)
employees >55 years				0.216	0.319
				(0.271)	(0.258)
former product inno.					0.255***
					(0.061)
former process inno.					0.122**
					(0.062)
sector dummies		***	***	**	***
regional dummies		-0.066	-0.057	-0.073	-0.052
		(0.063)	(0.063)	(0.064)	(0.062)
number of observations	248	248	248	248	248
Pseudo R^2	0.03	0.16	0.17	0.19	0.26

Significance levels : $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses.
Reference categories: competitors 6-20, unqualified employees, employees <30 years.

Table 4.10: Average Marginal Effects of Probit Estimations, Purpose of Social Software Use Reduced Sample

dependent variable: dummy for innovation					
	(1)	(2)	(3)	(4)	(5)
social software internal	0.183*	0.178*	0.211**	0.205**	0.142
	(0.095)	(0.094)	(0.092)	(0.091)	(0.094)
social software external	0.205	0.147	0.204	0.203	0.150
	(0.144)	(0.151)	(0.141)	(0.140)	(0.141)
social software both	0.289***	0.207**	0.256***	0.252***	0.227***
	(0.076)	(0.086)	(0.083)	(0.085)	(0.085)
firm size		0.070***	0.066***	0.072***	0.058**
		(0.025)	(0.025)	(0.025)	(0.024)
firm age		-0.010***	-0.009***	-0.010***	-0.009***
		(0.003)	(0.003)	(0.003)	(0.009)
IT intensity			-0.139	-0.244*	-0.259**
			(0.118)	(0.134)	(0.125)
competitors 0-5			0.071	0.062	0.032
			(0.079)	(0.079)	(0.075)
competitors >20			0.146**	0.133*	0.128*
			(0.073)	(0.074)	(0.072)
highly qualified empl.				0.341	0.166
				(0.243)	(0.230)
medium qualified empl.				0.199	0.024
				(0.226)	(0.215)
employees 30-55 years				-0.049	0.002
				(0.194)	(0.183)
employees >55 years				0.293	0.381
				(0.277)	(0.266)
former product inno.					0.266***
					(0.063)
former process inno.					0.089
					(0.064)
sector dummies		**	**	**	**
regional dummy		-0.068	-0.053	-0.078	-0.058
obs.	237	237	237	237	237
Pseudo R^2	0.04	0.16	0.18	0.19	0.27

Significance levels: $*$: 10% $**$: 5% $***$: 1%. Standard errors in parentheses. Reference categories: no social software, competitors 6-20, unqualified employees, employees $<$ 30 years.

5 Final Remarks

The aim of this thesis was to shed some light on the relationship between ICT, workforce age and firm performance. Therefore, it analysed how the age structure of the workforce is related to the adoption of new or significantly improved technologies and software and to the IT-enabled productivity in German firms. Furthermore, it showed how social software, belonging to the recent web-based technologies and applications termed web 2.0, is related to the probability of service innovation.

Compared to employees being younger than 30 years, an older workforce is negatively related to the probability of technology adoption in small and medium-sized ICT and knowledge-intensive service firms. Furthermore, the older the workforce, the less likely is technology adoption. The dispersion of the workforce age has no significant impact on the probability of technology or software adoption. However, in firms with enhanced teamwork, a homogenous workforce in terms of age is positively related to the probability of technology adoption. Thus, the success of age-mixed teams with regard to productivity found in the literature can not be transferred to the context of technology adoption.

Referring to small and medium-sized firms in the ICT and knowledge-intensive service sectors the results of the second chapter imply that these firms should employ young people and to build teams with employees being around the same age in order to keep pace with the technological development and to constantly adopt new or significantly improved technologies and software.

However, facing the demographic change and the accompanying decrease in young employees and at the same time the increase in aging workers, this seems not practicable. A solution to this problem might be constant training for the older workers, in particular IT-training. Furthermore, firms should internationalise their workforce and search for qualified young personnel abroad to meet with the expected skill shortages. These two measures could be important tools for firms to stay competitive in times of rapid technological progress.

Policy makers are in demand as well. They need to offer incentives for the ICT and knowledge-intensive firms to employ older employees and to relieve the pension system by supporting training measures for older workers. This can be done directly, for instance by sponsoring training measures, or compensating the firms for the labour slack emerging during employee training or indirectly via tax reductions for example. Furthermore, policy makers should encourage the immigration of young and qualified workers from abroad by lightening visa and immigration regulations. The increase in employment of younger workers would be an important step in disburden the social security system.

Increasing the employment of young and qualified workers and increasing the IT-skills of older workers might be a good mixture for the firms and the economy as a whole to stay competitive in a globalised world and technology-based environment.

Nevertheless, with regard to productivity, an ageing workforce does not represent a challenge. The third chapter reveals that employees aged 50 years or older are not less productive compared to the so-called prime age workers between 30 and 49 years. In contrast to employees being younger than 30 years who are less productive compared to the prime age workers. Furthermore, older workers using a computer are more productive than older non-computer users. Interactions between IT intensity and the proportion of older workers show no significant effects, thus, older workers do not lower IT-enabled productivity.

The results of the third chapter reveal that positive productivity effects owing to computer usage at the workplace are not restricted to certain age groups but do also exist for the case of older workers. This is in line with results from the skill-biased technological change literature showing that computer users are more productive than non-users, not because they use computers but because they are better qualified for using a computer. Thus again, firms should put more effort in qualifying older workers with regard to IT-skills. This might help to cope with the demographic developments and to keep older workers actively in the labour market. Policy makers should support firms training efforts for example with the above mentioned measures.

The fourth chapter deals with social software as part of the new web 2.0 applications. It reveals that ICT and knowledge-intensive service firms using social software are more likely to innovate. Taking into account former innovative activities of the firm and its previous propensity to adopt new technologies and to change processes, the analysis suggests a causality between social software use and innovation that runs from social software to service innovation.

This implies that the open and participative character of social software could allow the knowledge in the firm to be efficiently applied, to identify the idle knowledge and to combine it with existing knowledge. This leads to new knowledge and new ideas which could open out into innovation. Furthermore, the open and flexible external communication enabled by social software might allow external knowledge and customer requirements to flow into the firm where it can be transferred to new services. Thus, if firms apply social software, they alleviate the access to knowledge and thereby gain suggestions and innovation input. For managers, this implies that they can profit from the adoption of social software by becoming more innovative and thus strengthening their competitiveness.

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